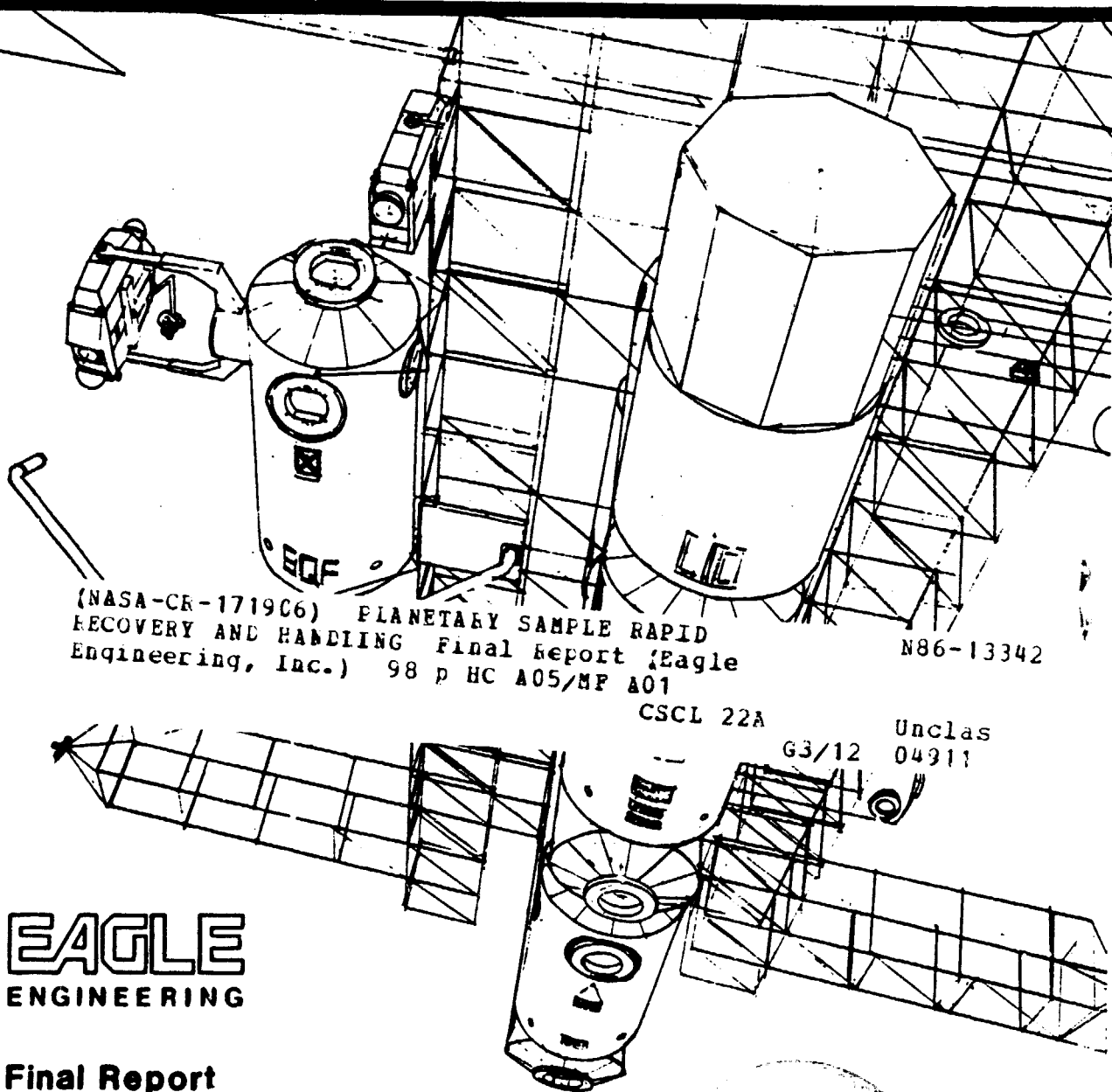


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Planetary Sample Rapid Recovery and Handling



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RECOVERY AND HANDLING Final Report (Eagle
Engineering, Inc.) 98 p HC A05/MF A01

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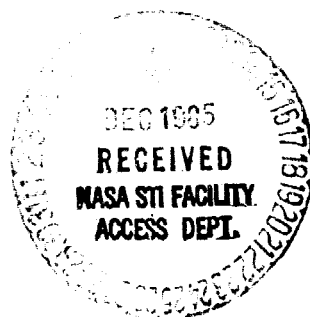
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EAGLE
ENGINEERING

Final Report
September 20, 1985

Report No. 85-105
Contract No. NAS 9-17176



**Planetary Sample Rapid Recovery and Handling
Final Report**

**Prepared for the Solar System Exploration
Division of the Johnson Space Center by
Eagle Engineering
Houston, Texas**

**Eagle Report No. 85-105
NASA Contract # NAS 9-17176
September 20, 1985**

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FOREWORD

This study was conducted between May and September of 1985 for the Solar System Exploration Division of the Johnson Space Center. The purpose of the study was to help planetary mission planners design methods for recovering and cost effectively handling planetary samples following return to the vicinity of Earth.

Dr. Donald L. Henninger was the NASA technical monitor. Extensive advise and supervision was also provided by Dr. Douglas P. Blanchard.

William R. Stump was the Eagle study manager for this effort. Gus R. Babb performed the orbital mechanics analysis. Franklin U. Williams did the thermal analysis and sample container conceptual design. Donald B. Sullivan did the cost analysis. Other engineering assistance was provided by Paul G. Phillips and John W. Kiker. Sketches and graphics were provided by Patrick R. Rawlings, Mark W. Dowman, David A. Carson, and John R. Lowery.

1.0 Summary

Three topics are addressed in this report: 1) A rough cost estimate was produced for each of a series of options for the handling of planetary samples following their return to the vicinity of Earth, 2) The difficulty of quickly (within hours) retrieving planetary samples from low circular and high elliptical Earth orbit was assessed, and 3) A conceptual design for a biological isolation and thermal control system for the returned sample and spacecraft was developed.

The following table shows a cost estimate and approximate risk of back-contamination of Earth with extra-terrestrial organisms for each of ten options for handling planetary samples in the vicinity of Earth. The costs shown below include only the recovery and handling of the sample following arrival in Earth orbit. The risk estimates assume a one in 100 chance that life exists on Mars or some other body and that it can survive transport, propagate on Earth, and do damage of significance. The rest of the risk (computed in Ref. 3) is associated with entry of these organisms into the biosphere through equipment or other failure. All biological risks are rough order of magnitude. Risk has not been studied in any depth, with the possible exception of direct entry (Option 1).

<u>OPTION</u>	<u>MEDIAN COST</u> (MILLION DOLLARS)	<u>RISK</u>
1 - Direct Entry	\$ 7.5M	1.67×10^{-6}
2 - Shuttle Recovery	\$ 162 M	1×10^{-8}
3 - Rec. to Station Structure	\$ 180 M	$< 1 \times 10^{-8}$
4 - Space Sta. Repackaging	\$ 419 M	" "
5 - Minimal Analysis at Station	\$ 533 M	" "
6 - Subsample Sterilized at SS	\$ 621 M	" "
7 - Separate Quarantine Mod.	\$ 822 M	" "
8 - Attached Antaeus Lab.	\$2,160 M	" "
9 - 1/2 Quarantined Station	\$2,160 M	" "
10 - Build Antaeus Space Sta.	\$6,104 M	" "

The cost of a sample handling container and a Planetary Receiving Laboratory is not included in the above costs. These costs are, on the whole, common to all options and add around \$14

million to each. In Option 10 the cost of the receiving laboratory might be greatly reduced. This cost reduction will not be significant in Option 10, however, because of the magnitude of the other costs. The share of Space Station costs was not charged to any option.

A risk of one chance in one million or in 100 million does not seem like a significant risk to the authors of this report. The lower cost Options, 1, 2, or 3, are, therefore, recommended. The risk assessments require more work, however.

The returned planetary samples must be kept at low temperature to remain in their original state. This may prove difficult in Earth orbit, particularly for the comet nucleus sample (to be kept at 100 degrees Kelvin). One of a number of solutions to this problem is to recover the samples in either low circular or high elliptical Earth orbit as quickly as possible. An attempt to determine how this might be done resulted in the following conclusions:

- O For samples returned to low circular orbit, rendezvous time of 6 to 8 hours may be possible.
- O For high elliptical return orbits, the minimum rendezvous is one (elliptic) orbit period (12 to 24 hours) plus 3 to 4 hours.
- O Retrieval by the Orbital Maneuvering Vehicle (OMV) requires that the sample be returned to low circular orbit.
- O A Centaur or Orbital Transfer Vehicle (OTV) class vehicle is necessary for retrieval from a high elliptical orbit.
- O A low circular orbit implies aerobraking of the sample return vehicle. Thus, a Centaur or OTV class vehicle is necessary for retrieval of a propulsively braked sample.

Operating from a Space Station, an OTV deployed to rendezvous with a sample in a high ellipse (12 hr. or more) begins to precess out of plane with the Space Station at $-3^\circ/\text{day}$ as soon as it boosts into the ellipse.

Since rendezvous, recovery, and return will take at least a couple of days and possibly up to a week, a plane change on return of from 10 to 20 degrees is necessary. Three methods are available to return to the base plane:

- A. The ellipse can be lowered to a 200 km circular orbit, reversing the differential regression rate. Approximately one week's wait at 200 km is required for each day spent in the ellipse, based on the 500 km Space Station orbit.
- B. Wait in the ellipse until the two orbits precess 360° relative to each other back into the same plane. This takes 8 weeks

at 28.5° inclination or 13 weeks at 56°.

- C. Use propulsive plane change. The worst case is where apogee is 90° from the line of the plane intersection and the plane change must be made at the semi-latus rectum point. For this case after a 3 day wait (10° plane change) the delta V for simply changing the plane is ~1.1 Km/sec. For a LO₂/H₂ stage such as Centaur or an OTV this means an increase in total weight of ~30% as extra fuel. For a Centaur with a 1 metric ton (MT) payload this would mean an increase in fuel load of about 3 MT. This would probably be an acceptable increase.

Differential precession will therefore increase the propellant requirements for retrieval from a high ellipse by up to 30 percent.

For all the options, the sample and perhaps the returned spacecraft must be thermally controlled and biologically isolated after rendezvous. The best approach for providing thermal control of the sample, if thermal control is needed after rendezvous, is to use the systems that will be used for thermal control during the "inbound" phase of the sample's flight. Those systems can be used by resupplying cryogenic fluid, such as liquid nitrogen, to a coolant loop. The other systems, such as insulation, fluid flow control, data records and processing, and heat exchangers would continue to operate as before. The OMV or OTV could plug in a liquid nitrogen line with automation shortly after rendezvous. The nitrogen can be vented through a high efficiency particulate air filter such as is now employed in the highest level containment labs. Once the sample and the spacecraft are retrieved, and perhaps analyzed, they must be returned to Earth. The lowest cost method to return the sample would be to remove it from the spacecraft, which would be left on-orbit or attached to the Space Station. The sample with coolant loops pre-placed inside the insulation and a liquid nitrogen supply, would then be returned to Earth in the Shuttle mid-deck. There is an increased biological risk of forward and back-contamination associated with this option, however.

In a more conservative approach the sample and spacecraft would be placed in a metal cylinder for transport to Earth in the shuttle cargo bay (see Figures 34 and 35). The cylinder would be sealed with an O-ring in hard vacuum, with the pressurization inlet and liquid nitrogen inlet and gaseous nitrogen vent lines all flowing through high efficiency filters to prevent forward and back-contamination. The sample would remain in vacuum during transport with liquid nitrogen input to the cooling loops as required.

This concept may be greatly changed in the final hardware, depending on a number of choices. The major conclusion of this conceptual design work is that the sample container and carrier

spacecraft that will return to Earth must be designed with the post-rendezvous handling of the sample in mind. Plugging in to an existing heat exchanger and sensor system is much more practical than trying to strip away insulation and install coolant loops and sensors on-orbit, particularly in the face of possible biological contamination of the outside of the sample container. Some weight penalty may be required for "plug in" handling.

2.0 Introduction

In the future, a number of samples of extra-terrestrial material may be returned to Earth by unmanned probes. An unmanned Mars sample return mission has been extensively studied (Ref. 1). Comet and asteroid sample return missions have also been studied. Reference 2, the previous report produced under this contract, contains a description, including weight statements, of sample return missions from Mars, the comet Kopff, and the asteroid Ceres. A NASA working group currently meets regularly to coordinate work on these sample return missions and a number of contracted studies are underway.

These mission planners are now trying to address the key problems and determine the required technology development for these missions. Three key problems are addressed in this report.

The biological risk of extra-terrestrial life to Earth is the first problem. There is a small chance that an extra-terrestrial micro-organism might be returned to Earth with the samples. The actual probability of life on Mars or other bodies is now generally considered to be low. This low probability estimate is based on a very limited amount of information, however. The risk is mostly associated with the Mars sample return mission, but should not be considered zero for sample returns from other bodies in the solar system.

If extra-terrestrial life is returned to Earth it would be unwise to allow its release into the biosphere. Experience with the introduction of new organisms into human communities and other plant and animal environments has occasionally been disastrous. The quarantine of people and products to prevent such occurrences is a common and expensive practice. Even a low probability of a great disaster is worth some thought.

Since the probability of life being returned and the probability of it thriving on Earth and doing significant damage seems low at present, such considerations have not driven sample return mission design, but must still be considered. Section 3.0 of this report lays out the options for handling returned planetary samples from the simplest direct entry to a large dedicated space station used to quarantine the samples. A first order cost estimate for each

of these options was then produced. These cost estimates and descriptions, plus an estimate of the biological risk associated with each option, will help planners make a technically sound, reasonably safe (in a biological sense), and economically feasible choice.

This study did not address the biological risk of each of the options. Reference 3 proposes a methodology for assessing the biological risk and some limited probability numbers for several options which are discussed in detail along with the descriptions of the options and their costs in Section 3.0. The Reference 3 numbers, along with some estimates of the authors are used to produce some more general risk estimates.

The second problem this study addresses concerns rapid recovery of the returned samples from Earth orbit. In terms of trajectories in the vicinity of Earth, there are three options for returned samples: 1) The sample can enter directly into the Earth's atmosphere and proceed directly to the surface to be slowed by parachute, 2) The sample is placed in low circular Earth orbit for pickup, and 3) The sample is placed in an elliptical Earth orbit with periods of 12 to 24 hours for later retrieval. To enhance the science return of the mission, the samples must be kept at low temperature -- around 100 degrees Kelvin for comet samples, 230 degrees Kelvin for a Mars sample, and less than 200 Kelvin for an asteroid sample. If the sample is placed in either low circular or high elliptical Earth orbit, there are indications that, due to the albedo of the Earth, the low temperatures, particularly in the 100 degree Kelvin range, may be difficult to maintain.

One way to prevent the samples from heating up is to retrieve them as quickly as possible and refrigerate them. This study addresses the difficulty of quick retrieval in Section 6.0. Quick retrieval (within one or two orbits) was generally found to require a Centaur class Orbital Transfer Vehicle (OTV). Section 5.0 addresses the thermal environment around Earth in an approximate sense. Maintenance of 230 degree Kelvin temperatures does not appear difficult, but 100 degrees Kelvin does.

Another way to prevent the samples from heating up is to refrigerate them with equipment carried to Mars and back on or around the sample container. Other contracted studies are underway at present to better define this option. Some preliminary work by other contractors has indicated that integral refrigeration using phase change materials may not be unreasonably difficult or costly in terms of weight.

The third problem concerns thermal and biological control of the sample once it is retrieved in Earth orbit or on the surface. Section 7.0 proposes a concept for thermal control of the sample after recovery using liquid nitrogen coolant that is plugged

into a cooling loop that is already an integral part (inside the insulation) of the sample container. Two concepts are considered. The simplest approach uses the original sample canister assembly as the container for thermal, vacuum, and biological control. If the exterior of this canister is considered to be contaminated, then a biological containment box is then placed around this assembly.

3.0 Description Of The Planetary Sample Handling Options

Figure 1 shows ten options for handling returned planetary samples. The options break down into three basic ideas: 1) The sample enters directly into the Earth's atmosphere from the interplanetary trajectory, 2) the sample parks in Earth orbit and is picked up by the Shuttle, and 3) the sample parks in Earth orbit and is retrieved to the Space Station.

3.1 Direct Entry

In this option the sample enters directly into the Earth's atmosphere and onto the surface, without being first parked in Earth orbit. Once entering the Earth's atmosphere, the sample is slowed with a heat shield to subsonic speeds and will probably need to maneuver some for targeting. One or more parachutes are then deployed. The sample then can be air-snatched by an aircraft using a technique that has been employed by the Dept. of Defense (DOD) and NASA to recover payloads. As an alternate, the sample could be recovered after surface impact on land or water.

The scenario assumed in this study for costing purposes was an overwater airsnatch involving three C-130 type aircraft, a radar picket, and surface ships for backup, all borrowed from the military. The median cost estimate for this option was \$7.5 million, which is made up mostly of aircraft and equipment costs, and labor. This estimate is only for the work unique to this option and is explained in more detail in the section on costs. It is by far the least expensive option but also has the most risk (see Table 1).

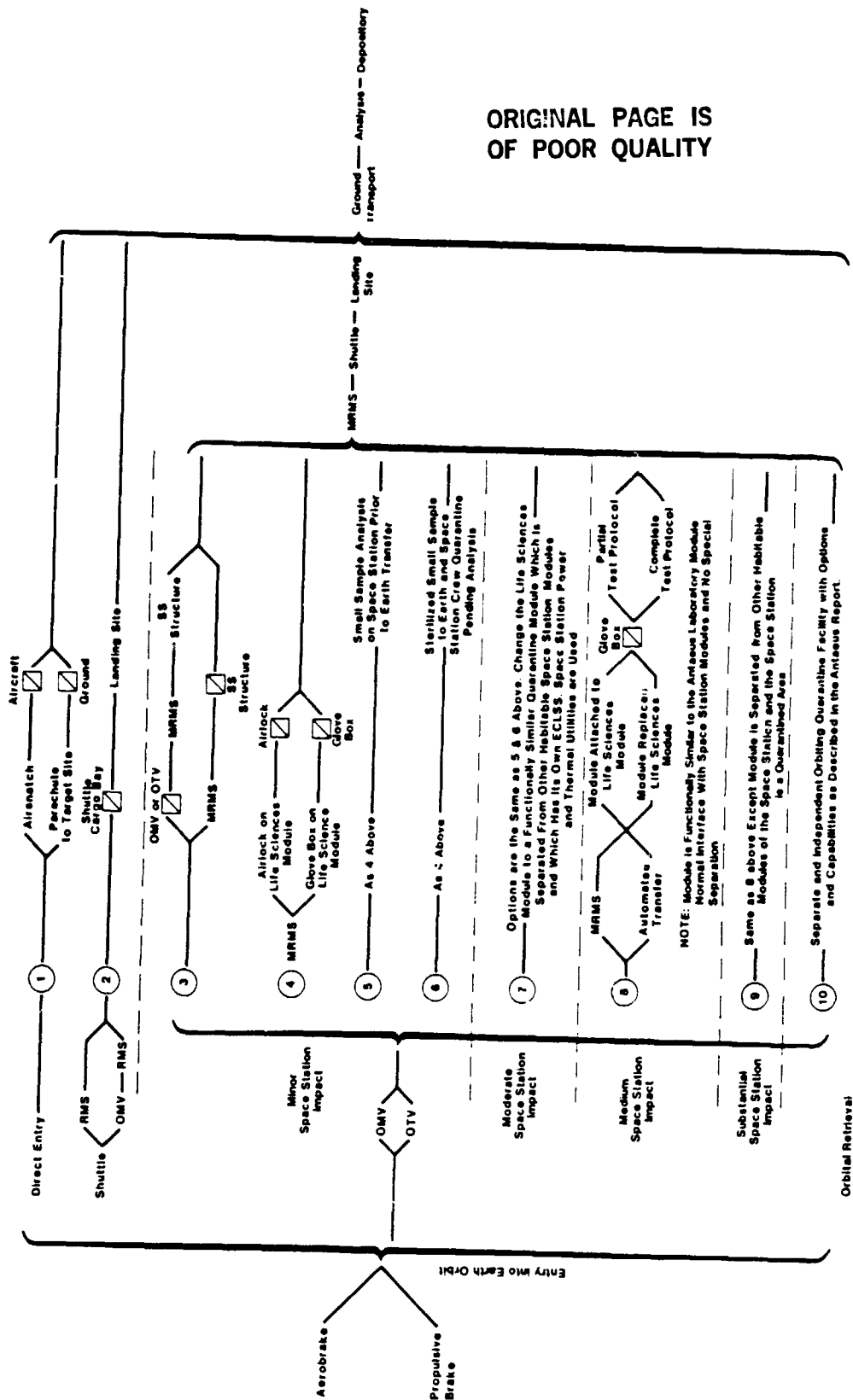
3.1.1 Design Trades

The technical issues with this recovery concern mass of the return vehicle and targeting. The return vehicle can enter at a steep angle and experience a high g load and little heating (a short heat pulse) or enter at a shallow angle and experience low g's and high heating (a long heat pulse). The steeper the angle, the easier targeting will become.

The heating and deceleration accompanying direct entry into the Earth's atmosphere introduces design problems for thermal protection and also problems in mechanical design, due to the forces encountered during reentry. Figures 2 through 5 plot g's, maximum surface temperature, maximum heating rate, and total heat input for a range of entry angles, velocities, and mass over $C_d \times$ frontal area. C_d is drag coefficient. The range of entry velocities and $m/(C_d \times A)$ is typical of the vehicles under discussion. The total heat input decreases, whereas g's increase with entry angle. For this mission, it is suggested that the entry angle be shallow enough to keep g's to 10 or below, in order to not crush

Figure 1

Options for Handling Planetary Samples in the Vicinity of Earth



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Figure 2

Maximum g's

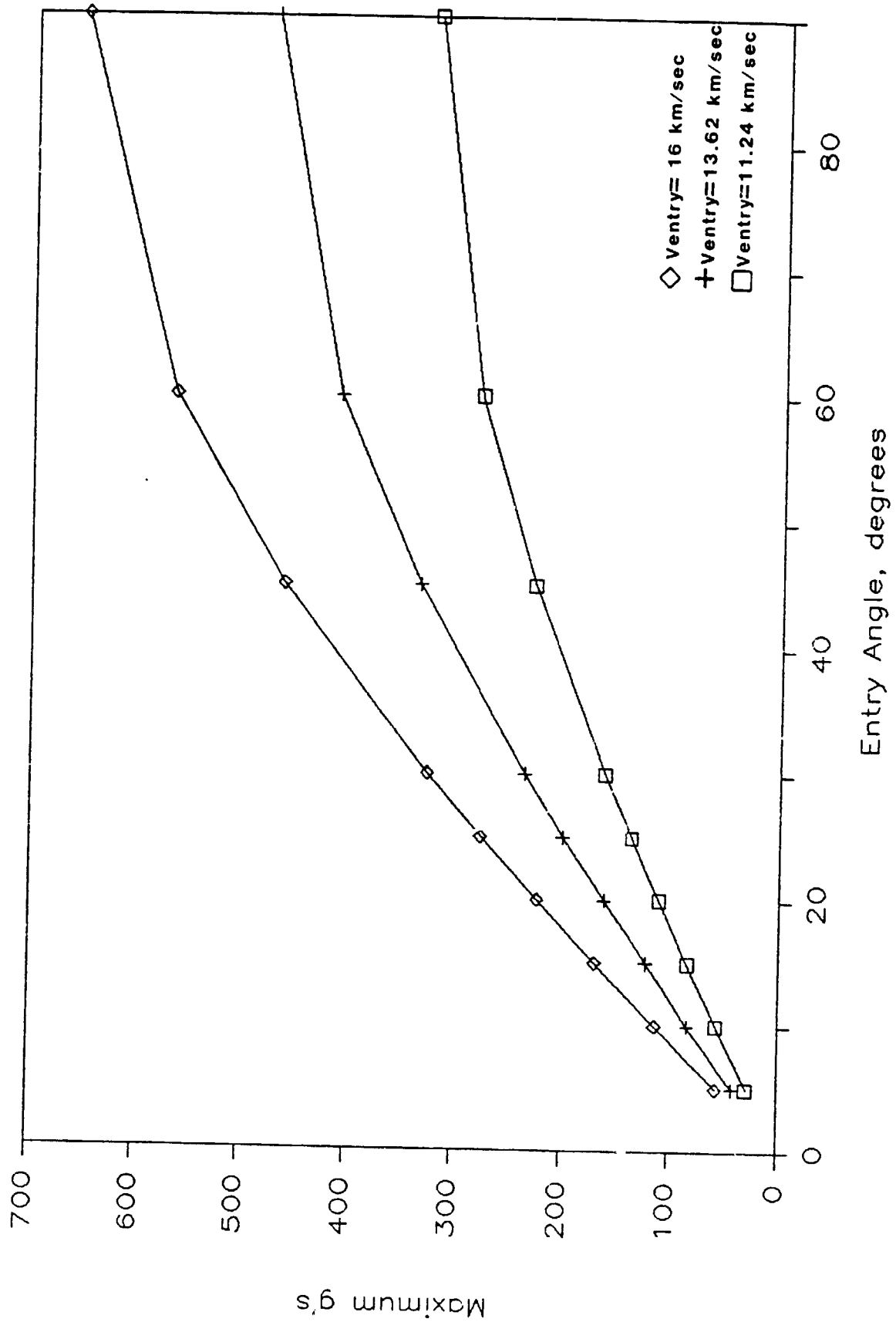


Figure 3

Maximum Temperature

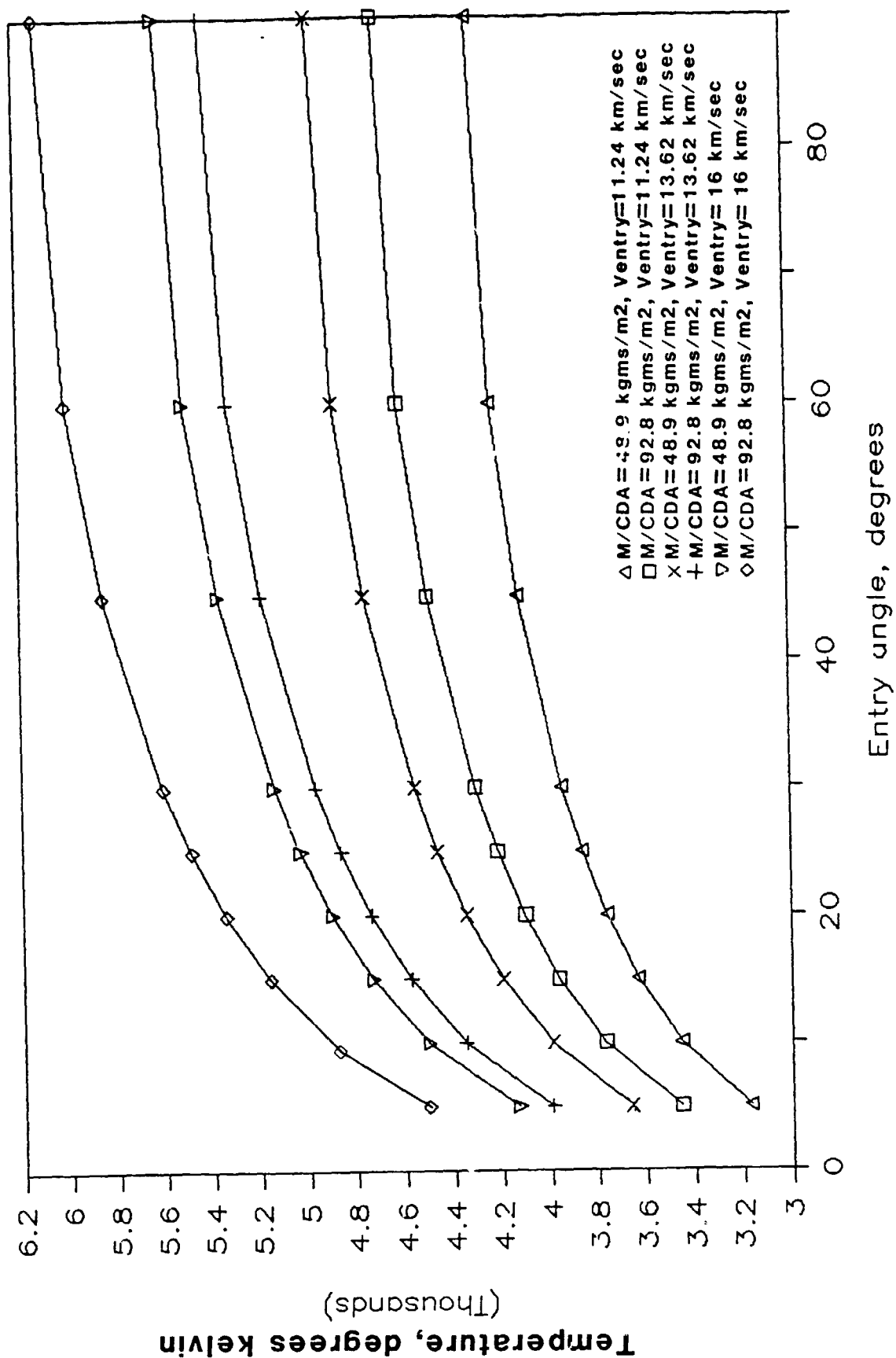


Figure 4

Maximum Heating Rate

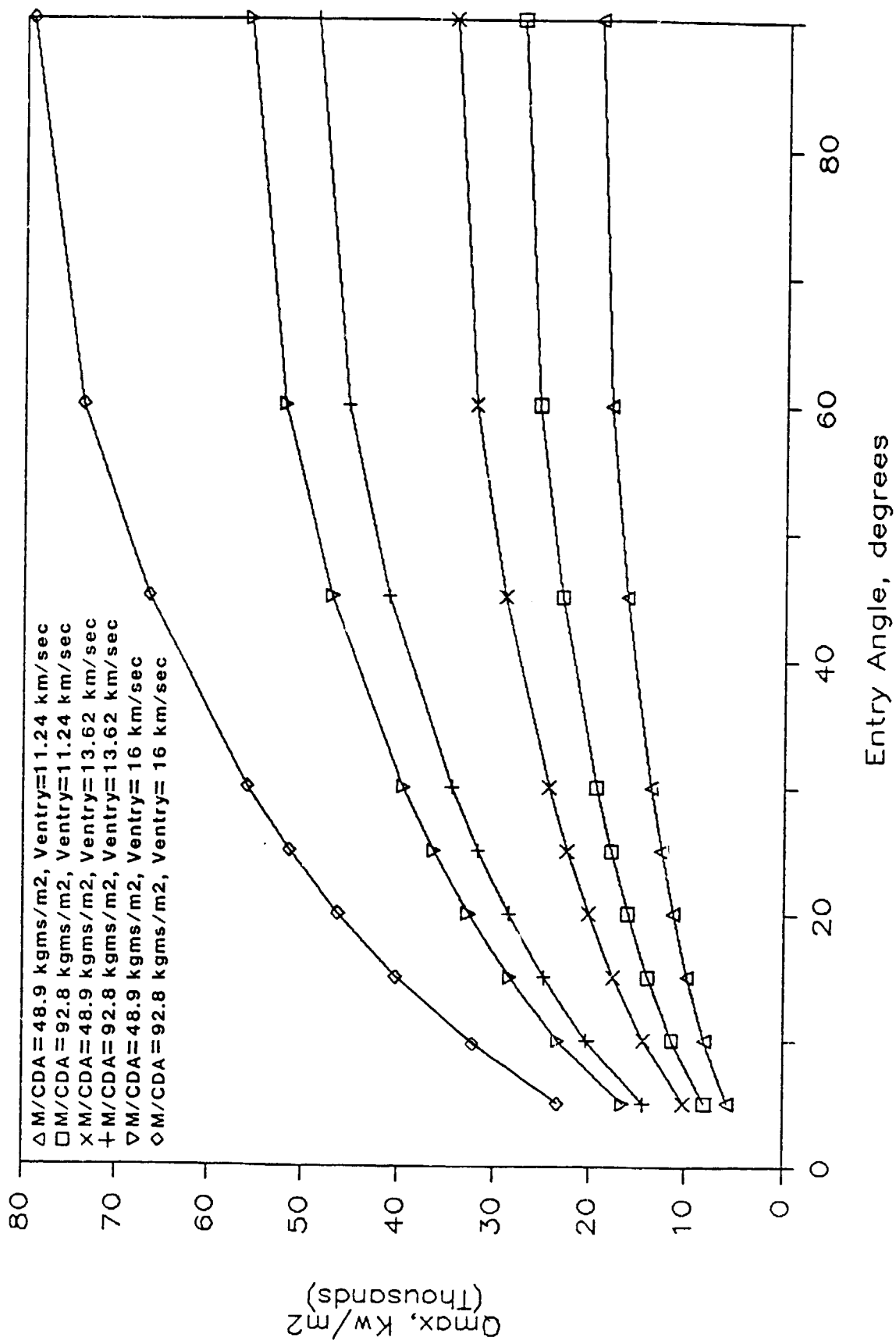
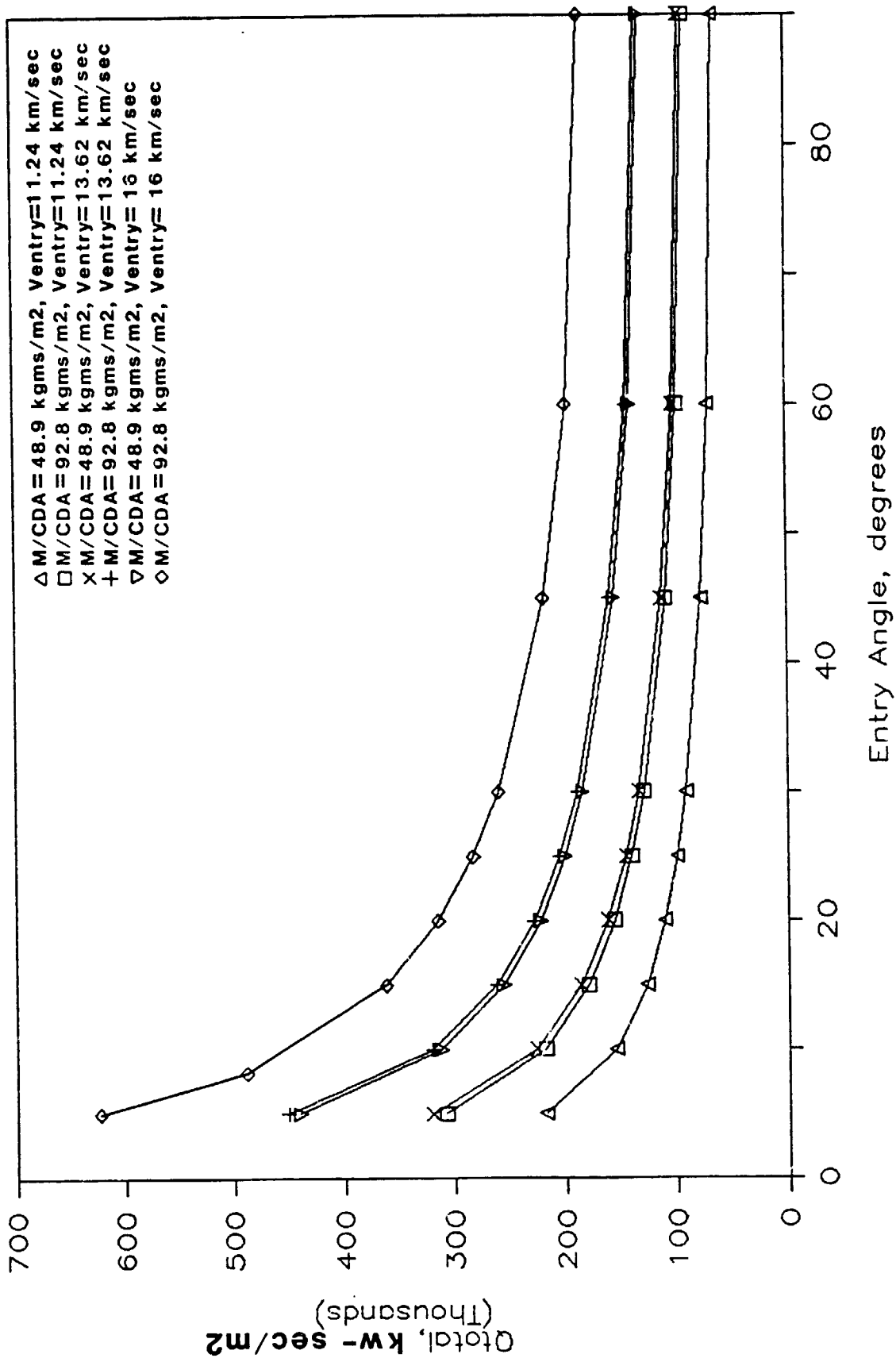


Figure 5

Integrated Heat Load



the sample. The g loads during burns should be compared to this number to determine if it is unnecessarily low. More g's may be needed to widen the corridor for guidance. The programs used to generate these figures are not directly applicable to entry angles less than five degrees, but can be used to indicate trends and limits and permit a crude approximation of the ablator necessary for the direct entry vehicle.

Figures 2 through 5 assume a zero lift configuration. In general, a vehicle with some lift will have a lower maximum heating rate (Q) and a higher total Q for a given mass/CdA. Phenolic nylon ablator over the entire surface of the entry vehicle is chosen as a baseline. The thickness should be approximately 6.35 cm and the mass per unit area 76.26 kg/m². This should prove to be conservative for the entry angles and velocities that are anticipated. The study to define the heating regime in more detail is beyond the scope of this effort. The ablator should be an incremental weight to the planned internal structure and insulation. The true entry angle, entry velocity, and corridor are not available at the time of this writing. The ablator estimate provided is for a 13.62 km/sec entry velocity, a 5 degree entry angle, and a mass/CdA of 49 kg/m². The vehicle is assumed to require this ablator over its entire aerosurface. Zero lift was assumed. Better knowledge of the flight control and entry constraints might allow the ablator mass to be reduced by as much as 50 percent.

This estimate should not be considered design detail. It is produced to allow a rough estimate of the mass of the direct entry vehicle.

A parachute system will be required to slow the vehicle for landing or airsnatch. A preliminary sizing, using a primary chute with a backup, a hung mass of 70 kg, and a descent rate of 10 m/sec resulted in a 5.5 meter diameter primary chute. The chute and mechanisms should weigh between 4 and 5 percent of the hung mass.

Targeting may be a challenge for direct entry, particularly if a land surface recovery is proposed. It will probably be easy to predict approximately where the vehicle will land some period of days prior to the entry, but it may be more difficult to target with some assurance of success for a given small area at the departure of the vehicle from its planetary body. This difficulty may make overwater airsnatch the preferred option.

3.1.2 Mass Estimate

The direct entry case is by far the least expensive option in terms of handling in the vicinity of Earth. The effects of this option on the rest of the mission must be determined, however, to see how the total program cost changes. The key number in

this determination is the mass of the direct entry vehicle as compared to the mass for other options. Figures 6 and 7, taken from References 5 and 4, respectively show vehicles designed to aerobrake Mars and comet nucleus samples into Low Earth Orbit.

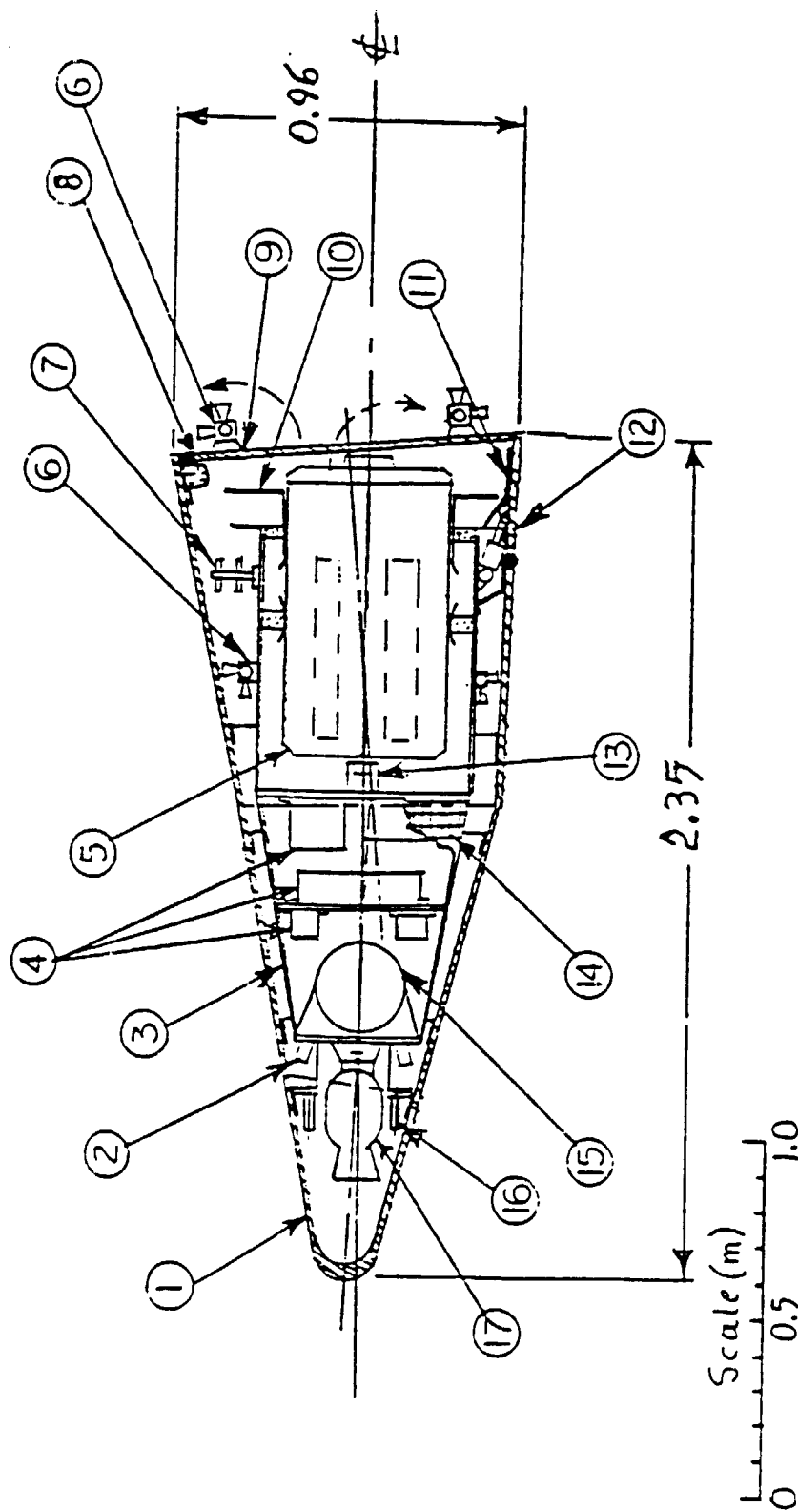
Table A-1 (located in the Appendix) is a weight statement for the comet nucleus vehicle that aerobrakes into Low Earth Orbit (LEO). Table A-2 shows how this weight statement might be changed for direct entry. The major change is the heat shield. The aerobraked vehicle to be circularized in LEO was 230.2 kg. The direct entry vehicle is estimated to be between 260.2 to 389.2 kg, all the uncertainty being in the heat shield. A better definition of the direct entry heat shield is needed to determine a more precise mass for this vehicle.

Table A-3 shows the same situation for the Mars sample return mission. The aerobraked vehicle is 138.5 kg, and the direct entry vehicle (Table A-4) is from 219 to 348.3 kg. Again, the heat shield is the major difference and the major uncertainty.

To better define the heat shield, the trajectory and g constraints must be defined, the internal temperature limits at the insulation interface must be specified, and the guidance, navigation, and flight control capabilities of the entry vehicle determined.

Figure 6, Aerobraked Comet Sample Return Vehicle (taken from Ref. 5)

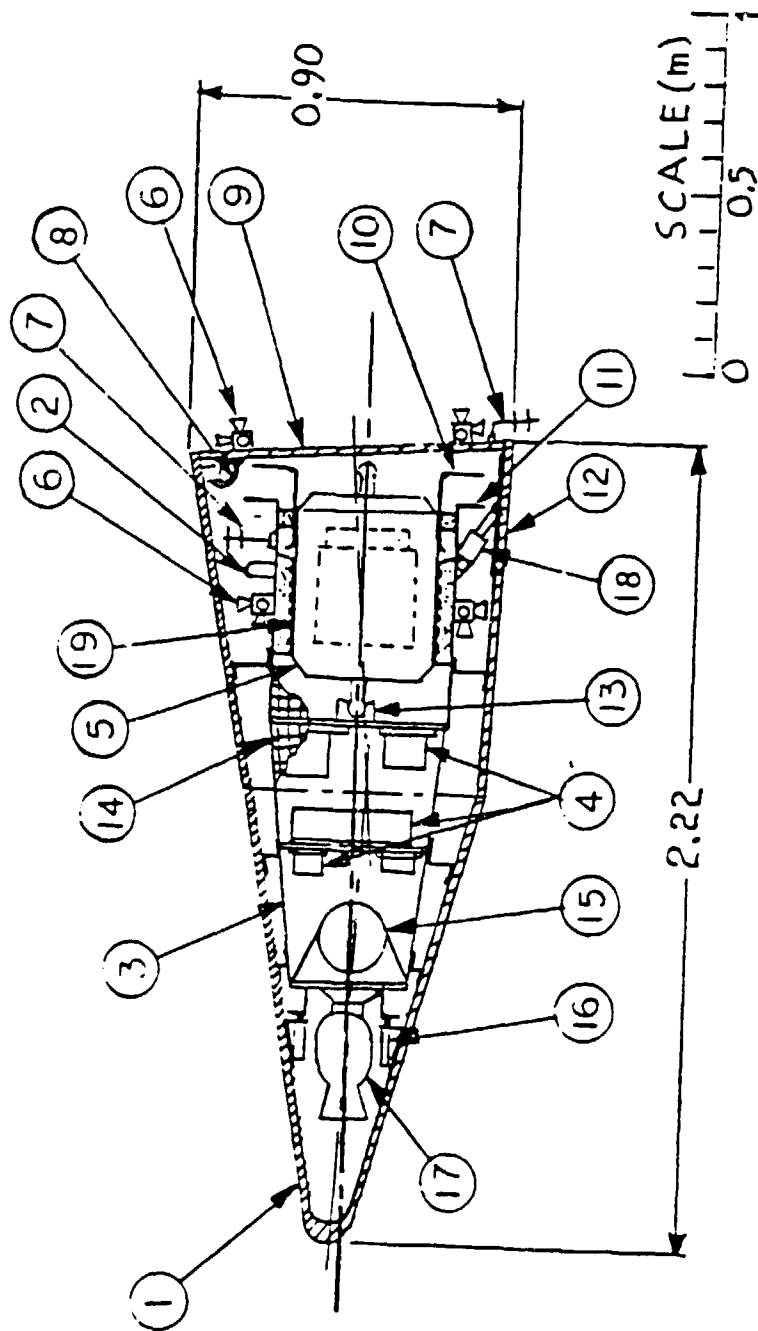
CNSR'85 STUDY **Earth Aerocapture Capsule (EAC)**



- | | | |
|--------------------------------|-------------------------------|---|
| 1 - AEROSHELL | 7 - OMNI ANTENNA | 13 - SCA RETENTION/RELEASE |
| 2 - SUN SENSOR (3) | 8 - AFT SHIELD HINGE DRIVE | 14 - SOLAR ARRAY (CIRCUMFERENTIAL) |
| 3 - BUS | 9 - AFT HEAT SHIELD/COVER | 15 - NITROGEN TANK (ATT.CTL., COOLING) |
| 4 - EQUIPMENT | 10 - FLAT PLATE RADIATOR | 16 - SEPARATION SPRINGS (3) |
| 5 - SAMPLE CANISTER ASSY.(SCA) | 11 - FLAP BACKING HT. SHIELD | 17 - SOLID ROCKET MOTOR (STAR 6), FOR ORBIT CIRCULARIZATION |
| 6 - THRUSTER ASSY.(4) | 12 - FLAPS WITH ACTUATORS (2) | |

Figure 7, Aerobraked Mars Sample Return Vehicle (taken from Ref. 4)

EARTH AEROCAPTURE CAPSULE (EAC)



- 1 - AEROSHELL
- 2 - SUN SENSOR
- 3 - BUS
- 4 - EQUIPMENT
- 5 - SAMPLE CANISTER ASSY.(SCA)
- 6 - THRUSTER ASSY.(4)
- 7 - OMNI ANTENNA (2)

- 8 - AFT SHIELD HINGE DRIVE
- 9 - AFT HEAT SHIELD/COVER
- 10 - FLAT PLATE RADIATOR
- 11 - SUNBAFFLE
- 12 - FLAPS (2)
- 13 - SCA RETENTION/RELEASE DEV.
- 14 - SOLAR ARRAY (BODY MTD., STRIP)

- 15 - NITROGEN TANK (ATT.CTL.)
- 16 - SEPARATION DEVICES (3)
- 17 - SOLID ROCKET MOTOR(STAR6),
FOR ORBIT CIRCULARIZATION
- 18 - FLAP ACTUATORS (2)
- 19 - BRUSH-CONTACT / SUPPORT ASSY.

3.1.3 Biological Risk

Direct entry is the only option that has been studied from a biological risk standpoint, and it was a good choice because it should have the highest risk of all the options. Reference 3, by Merkhofer and Quinn (1977), estimates a probability of back contamination from a direct entry Mars sample return mission of 1 in 6,000 (.0001667) for a reference mission that is essentially the same as our direct entry case.

The authors of Reference 3 truly developed a methodology for assessing these probabilities and point out that since the direct entry Mars sample return system was not yet (and still is not) designed, the numbers calculated are really only an illustration of their methodology.

The probability of back-contamination in Reference 3 is narrowly defined. It is assumed "that life on Mars exists, can survive transport to Earth, and propagate in the Earth's biosphere." The probability numbers calculated in Reference 3 only include the probability that Martian organisms collected and returned alive would, prior to their delivery to a Planetary Sample Receiving Lab (PSRL), be inadvertently released into the Earth's biosphere and would survive the release. The probabilities computed do not include the risk of back-contamination that might exist following delivery of the sealed sample to the PSRL.

In view of the Viking experience, the probability of life on Mars seems low. The authors of this report will arbitrarily assign a probability of one chance in 100 for the existence of life on Mars that can survive transport, propagate on Earth, and do significant damage on Earth. This seems like a conservative estimate, but it is based on limited data. This changes the previous probability of contamination (one chance in 6,000) to one chance in 600,000 or 1.667×10^{-6} .

"Nearly all of the contamination risk is due to events occurring during Earth entry and most of this is due to the risk of failure of the parachute system designed to slow the Earth-entry capsule. A number of essentially independent sources of risk contribute to the probability in the range of 10^{-6} to 10^{-5} . As a consequence, it is difficult to reduce the probability of potential back-contamination for the reference mission below 1 in 100,000 without simultaneously improving or eliminating a large number of risk sources." (Ref. 3)

3.2 Shuttle Recovery

In this option the sample is aerobraked or propulsively braked into a low circular orbit. In current baselines, aerobraking is the plan. Propulsive braking into Low Earth Orbit would be much more expensive in terms of return vehicle mass. Figures 3

and 4 (taken from References 4 and 5) show the Mars and comet aerobraked sample return vehicles prior to aerobraking into Earth orbit.

The aerobraked vehicle goes into the atmosphere to dissipate velocity aerodynamically and then comes out of the atmosphere and is circularized with a small solid rocket such that it does not enter the atmosphere again. Prior to this circularization burn, the aeroshell is discarded to reduce the mass that must be circularized, and to decrease the thermal problems associated with keeping the sample cold. This aeroshell will enter the Earth's atmosphere on the next orbit and may survive to impact the surface. Some risk of organisms riding this aeroshell to Earth exists and should be assessed.

Following circularization of the sample with the aeroshell removed, it will be recovered to the Shuttle. The simplest option would be for the Shuttle to rendezvous with the sample directly, grapple it with the Remote Manipulator System (RMS) and place it in a container that provides biological containment and cooling in the payload bay. The RMS or a suited crewman would then hook up a liquid nitrogen cooling line to the heat exchanger or coils already in the sample canister and the box would be sealed. A concept for this payload bay container is explained in more detail in Section 7.0.

A less expensive variation of this option would be to remove only the sample from the returned spacecraft, perhaps with an astronaut in a spacesuit doing the work. The sample would then be returned to Earth in the Shuttle mid-deck and the Earth return vehicle spacecraft would be left in orbit.

There are two disadvantages to this plan. The biological risk might be significantly increased and the spacecraft might enter the atmosphere in an uncontrolled manner at some future date.

It may not be possible to circularize an aerobraked sample return vehicle in a Shuttle accessible orbit. Guidance, Navigation and Control (GN&C) factors may require that the vehicle be circularized in some orbit higher than 500 km (270 nm). Targeting to low orbits may be difficult for an aerobraked vehicle. If this is the case, the Shuttle will deploy an Orbital Maneuvering Vehicle (OMV), a small remotely operated vehicle (see Figure 10) with limited range and performance. Section 6 describes how this type of recovery might be achieved in a few hours.

The Shuttle and OMV would be prepositioned in the target plane prior to arrival of the sample vehicle at Earth. Following arrival of the vehicle, the OMV would be deployed and conduct phasing maneuvers. Following rendezvous of the OMV and the sample vehicle, the OMV would dock with the sample vehicle and plug in a liquid nitrogen supply, if needed, for thermal control.

The OMV would then return the sample vehicle to the Shuttle where liquid nitrogen cooling would be connected, if needed, and the entire sample vehicle and nitrogen bottle placed in a biological containment box in the payload bay. Even though the mass and dimensions of the sample vehicle (2.5 m long, 1 m diameter, 140 to 230 kg) are small, and the OMV is not large, it is probable that this will be a dedicated flight because the schedule, plane, and orbital altitude of the Shuttle will be tightly constrained by the recovery requirements if a recovery is to be performed quickly (within hours). These constraints relax as the time available to recover the sample becomes greater.

Phase B studies of the OMV by TRW, LTV, and Martin are nearing an end. Phase C/D is planned to start in 1986.

Another variation on this option is recovery of the sample from a high elliptical orbit with a Centaur deployed from the Shuttle. OMV recovery is not possible from the 12 or 24 hour period ellipses. If aerobraking proves difficult or expensive, the samples may be inserted into a high apogee elliptical orbit with solids. A Shuttle deployed Centaur or other OTV will be required to retrieve them. The OTV replaces the OMV in this scenario. Figure 8 and 9 (from Ref. 1) show a conceptual design for a propulsively braked sample vehicle that would be inserted into an elliptical orbit.

The cost estimate assumes that the sample can be returned by aerobraking to an orbit that the Shuttle can reach, at worst with an OMV. The median estimate is \$162 million, most of which is for a dedicated Shuttle flight. An OMV might add another <\$1 to \$3 million, a Centaur \$50 to \$100 million.

Reference 3 estimates the risk of back-contamination (using their narrow definition of back-contamination which assumes Martian life exists, etc, as explained in 3.1.3) as about one in one million or 1×10^{-6} . This risk does not include the potential hazard of the aeroshell which is discarded and enters uncontrolled. Assuming that the aeroshell is recovered, and a one in 100 chance of Martian life, etc., a less constrained prediction of the risk of back-contamination becomes one in 100 million or 1×10^{-8} . This seems very safe. The authors of Reference 3, who were developing a methodology more than an estimate, did not study this case in detail, however. It was apparently an add-on at the end of their study, which took the direct entry case as a baseline.

Figure 8, Propulsively Braked Earth Orbit Capsule (taken from Ref. 1)

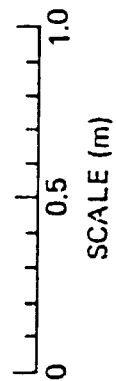
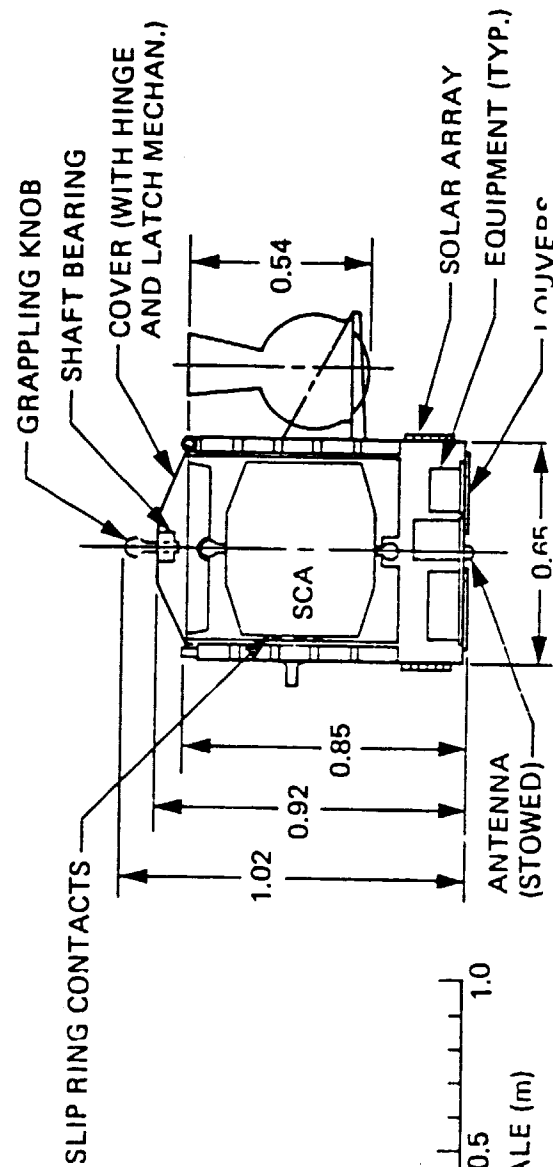
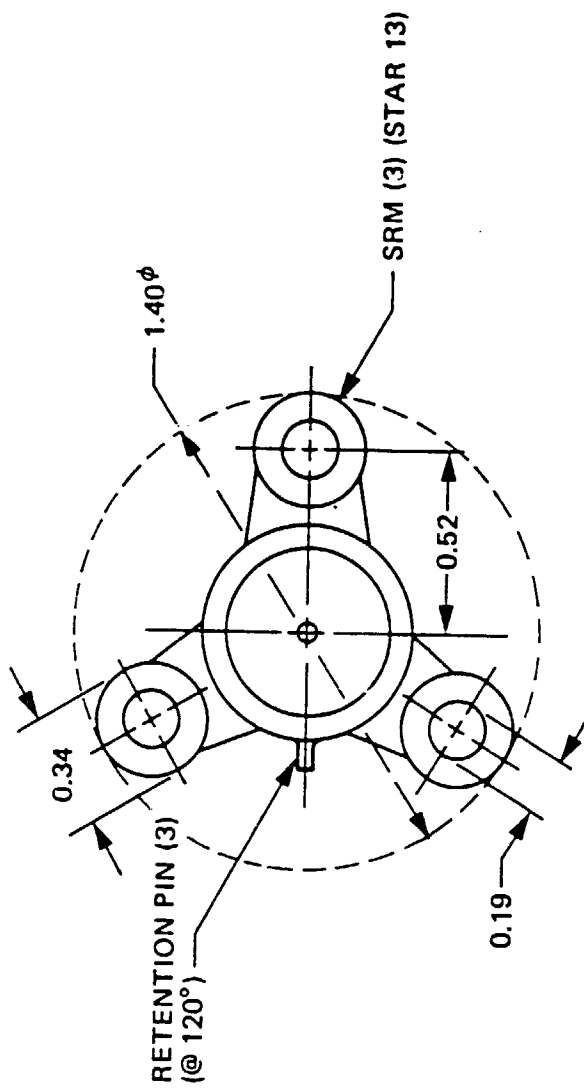
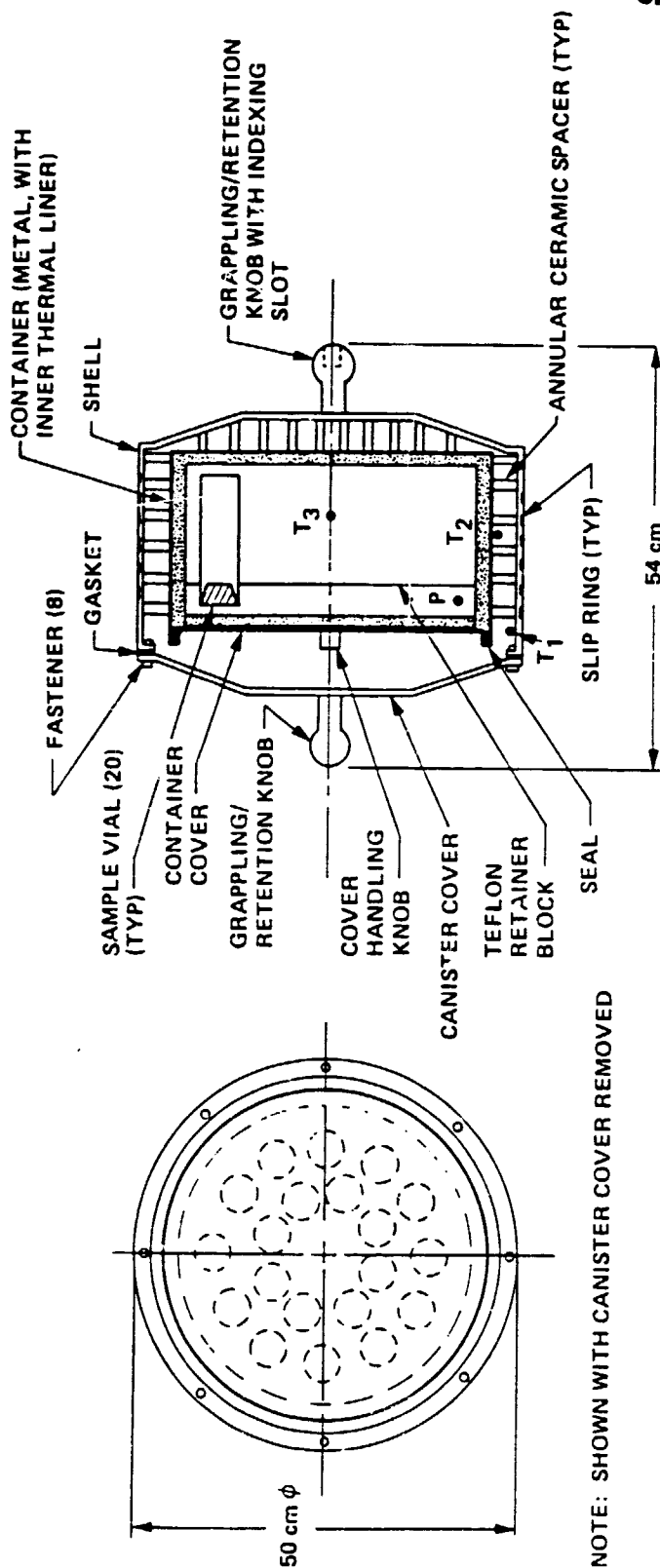
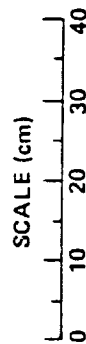


Figure 9, Sample Canister Assembly (taken from Ref. 1)



NOTE: SHOWN WITH CANISTER COVER REMOVED



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NOTES:

T₁, T₂, T₃ = PT RESISTANCE THERMOMETERS

P = T/C GAUGE (VACUUM SENSOR)

TRANSDUCER EXCITATION APPLIED ONLY WHEN SAMPLING,
TO MINIMIZE HEAT BUILD-UP

3.3 Retrieval to the Space Station Structure for Pick-up

In this option, the sample vehicle is retrieved to the Space Station by an OMV, OTV or Centaur. The sample is aerobraked or propulsively braked into a circular or elliptical orbit in the Space Station plane. Recovery from an elliptical orbit requires an OTV or Centaur and special consideration of orbital precession rates (see Section 6.7). Taking the scenario used for costing, an OMV, with the help of an EVA crewman or PMS places the sample in a biological isolation container supplied with liquid nitrogen, and located on the Space Station structure, to await pick-up by the Shuttle. The sample never enters the Space Station modules.

A variation on this option which might further reduce the biological risk is for the OMV or OTV to take the biological isolation container to the sample vehicle instead of bringing the sample to it.

The median cost estimate for this option was \$180 million. This is largely the cost of one STS mission to bring up equipment and recover the sample.

The risk of back-contamination (using the more general definition and Ref. 3 numbers) should be less than one chance in 100 million. No analysis of risk was performed for this option or any of the following more complicated options. It is simply assumed that the more elaborate precautions involved in them will result in a risk less than that for a direct Shuttle recovery (one chance in 100 million).

3.4 Recovery to the Space Station for Repackaging

This option is similar to the previously described option, in which the sample is only retrieved to the Space Station and then sent on to Earth, but in this option, the sample is placed in the Life Sciences Module airlock. The sample is removed from its carrier spacecraft, perhaps with manipulators while in the airlock, or perhaps inside a glove box that attaches to the door of the airlock. The sample container, stripped of insulation, is then placed in a much smaller biological isolation and thermal control container that might be carried in the Shuttle mid-deck. The remaining spacecraft and other parts are kept in quarantine in the airlock or glovebox, pending analysis of the sample on Earth.

No analysis is performed on the Station in this option. The Life Sciences Module, in which the sample is repackaged is connected to the rest of the Station by pressurized passageways and tied to the overall environmental control and life support system.

In the event that no active thermal control is required for the sample prior to arriving at the Space Station, this option might facilitate a minimum mass sample canister assembly and spacecraft

because no OMV/OTV interface other than a grapple fixture, would be required.

Another way of viewing this option is that a large biological isolation and thermal control unit for the entire returned spacecraft, which would have to ride in the payload bay, is traded for modifications to the Life Sciences Module airlock to allow repackaging.

A variation of this option would be to attempt repackaging with an RMS or an EVA crewman with an "oversuit" for biological isolation, and thus avoid modification to the airlock door.

The median cost estimate for this option was \$508 million, consisting primarily of up to two dedicated Shuttle flights and a \$100M to \$250M modification of the airlock and other structures.

3.5 Recovery to the Space Station with Minimal Analysis of the Sample

This option is similar to the previous one, except in this case a small subsample is removed at the Space Station and some initial analysis performed on it in a glove box in the Life Sciences Module prior to the main sample being sent to Earth. There is some question as to how much use a minimal analysis would be. It might consist of simple observation with a light or electron microscope, looking for evidence of life or organic matter, alive, dead, or fossil. The difficulty involved in doing this analysis in zero g is uncertain.

This option was felt to be essentially the same as the previous one with some increase in cost due the analysis procedure to be performed so the median cost was estimated to be \$533M, slightly higher than the previous option.

3.6 Recovery to the Space Station with a Small Sample Sterilized and Sent to Earth

This option is, again, essentially the same as the previous one, except that the subsample is sterilized, probably with heat, so that it can be sent to Earth with no risk. The main sample is held pending Earth analysis of the small sample and the Space Station crew might be quarantined until the small sterilized sample is studied on Earth.

For the organisms with which we are familiar, sterilization is probably easier than analysis in zero g. The characteristics of an extraterrestrial organism are uncertain, though it will almost certainly have some means of handling the temperature and radiation extremes that are characteristic of the bodies of interest. This may cause a high temperature to be used for sterilization. The difficulty comes in choosing this temperature low enough such that some evidence of an organism might still remain following sterilization.

Another difficulty with this option is deciding what to do if evidence of life is found. A low cost method might be to wait until such evidence is found to provide analysis equipment on-orbit or quarantine facilities on Earth. Given the long lead times and serious thought that must be invested in such an analysis, this strategy may not be practical. On the other hand, the odds seem heavily in favor of no life, and if it is found it may require analysis techniques totally unknown to us at present.

The median cost estimate for this option is \$533 million, which is the same order as the previous option with an increase for a sterilization device.

3.7 Recovery to a Separated Quarantine Module

The sample/spacecraft is returned to the Space Station and docked with specially designed automation which places the sample in a glove box in the Quarantine Module. The Quarantine Module is a Life Sciences type module outfitted for planetary sample handling, which is temporarily separated from the rest of the Station by vacuum. The Quarantine Module has its own ECLSS but uses Station power and thermal control. Figure 10 shows an OMV bringing a sample to a Quarantine Module.

The Quarantine Module is not connected to the rest of the Station when it is functioning as a planetary sample handling facility. When the Module is not doing sample work, it might be reconnected to the rest of the Station and serve other purposes, or it might be returned to the Earth surface in the payload bay with the sample inside it each time its services are required.

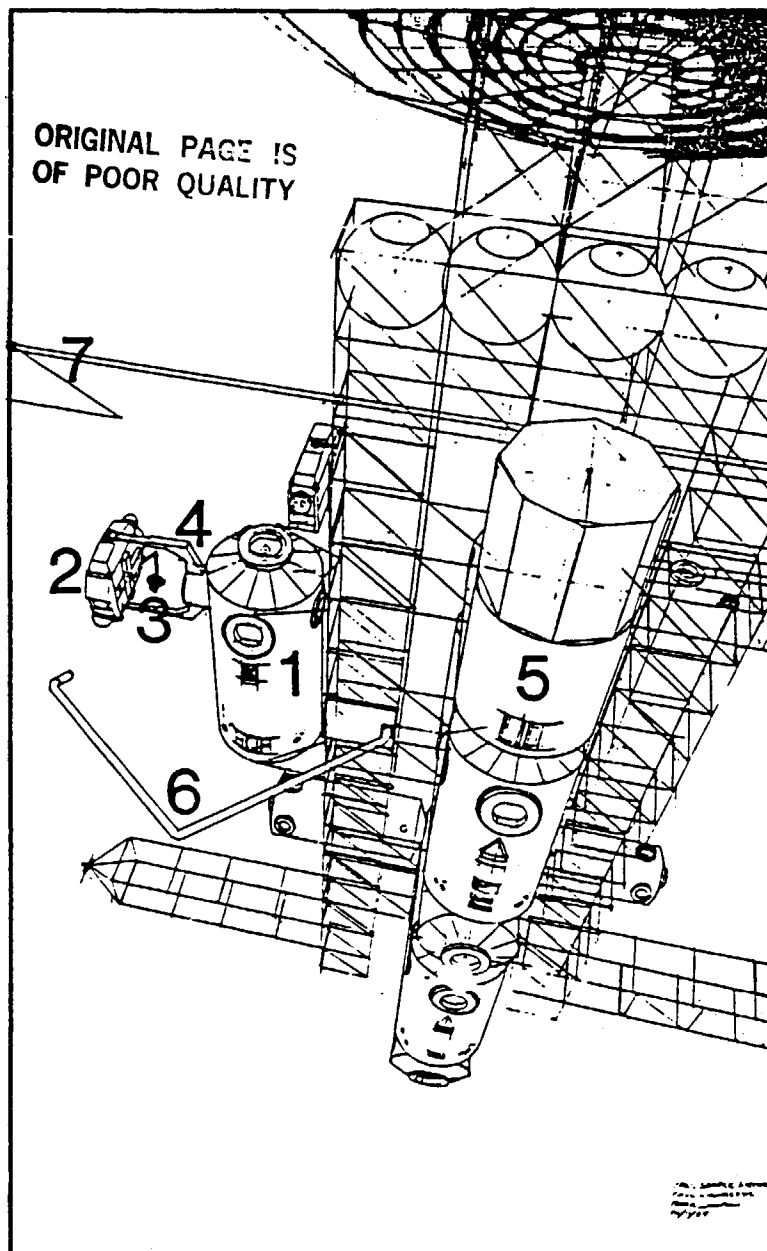
Dedicated facilities and facilities with special hardware will seem more reasonable if a number of sample return missions are envisioned. Manned Mars missions might also use a Quarantine Module.

The Quarantine Module could be used to take a subsample, sterilize a subsample, or do minimal or perhaps more complete analysis.

The median cost estimate was \$822 million, consisting of up to three Shuttle flights and \$200 to \$350 million for the Quarantine Module.

Another variation on this option is to load the entire Quarantine Module into the payload bay, following retrieval and initial analysis of the sample, and return the Module with the sample inside it to Earth.

Figure 10, OMV Brings Sample to Quarantine Module



OMV DELIVERS SAMPLE TO QUARANTINE MODULE

- | | |
|------------------------------|--|
| 1. QUARANTINE MODULE | 5. OTHER MODULES OF GROWTH SPACE STATION |
| 2. OMV | 6. MOBILE RMS |
| 3. RETURNED PLANETARY SAMPLE | 7. RADIATORS |
| 4. AIRLOCK/OMV HARD DOCK | |

3.8 Recovery to a Space Station Antaeus Lab Module

The sample is placed, with automation, in a glove box in a special module. The Life Sciences Module of the Station is replaced with an Antaeus Laboratory-type Module capable of performing a lengthy protocol on a subsample. The Antaeus Laboratory Module is described in some detail in Reference 7, which describes a space station primarily designed and dedicated to planetary sample quarantine and analysis. Reference 7 also contains a protocol for testing returned samples in space. Part or all of this protocol can be performed in this module. The sample can be analyzed in this module over a long period. After it is proven safe in space it is returned to Earth. If it is proven to be unsafe, this module and perhaps the entire Space Station might be abandoned and boosted to a higher orbit.

Assuming the worst case scenario of a contaminated, malignant organism escaping into either the Space Station or a module of the Space Station, the problem becomes that of either placing the controllable elements into a high circular orbit that will be stable for a very large number of years, or boosting them to escape. Approximately the same propulsive capability is required for either option.

To achieve escape with either solid or storable liquid propellant, a 250 ton propulsion stage is required for the 100 ton Space Station or a 40 ton stage for the single module. With LO_2 propellant, these propulsion requirements are 120 tons and 20 tons, respectively. Thus, a single extra large Centaur could dispose of a single module. Single stage operations are required so that no contaminated pieces are left behind.

An OMV could boost the entire Space Station orbit up 150 kilometers (81 N.M.) or a single module 770 kilometers (441 N.M.). This should add sufficient orbital lifetime to allow development of a large stage for propellant disposal.

This Antaeus Lab Module is just one module added on to or replacing the Life Sciences module. It will be connected to the Station via pressurized passageways.

The median cost estimate for this option was \$2,160 million which included over \$1 billion for the development, production, and operations of this new module. Three or four dedicated Shuttle missions were also assumed.

3.9 Recovery to a 1/2 Quarantined Space Station

This option is almost the same as the previous one. As with the previous option, an Antaeus-type Laboratory Module is joined via pressurized passageways to the rest of the Space Station. In this case, however, other modules used to support the lab crew

are quarantined, pending analysis of the sample. This option is somewhat more biologically safe than the previous option. One module alone (the Antaeus Lab Module) cannot be easily used to quarantine crew working in it. By designating several other modules for use by the analysis crew only, and placing them all in quarantine by closing airlock doors and dropping the pressure in the quarantined area slightly below that in other areas, the effect of the Antaeus Space Station (Ref. 7), might be produced with only part of the planned Space Station.

The median cost was \$2,160 million, the same as for the previous option.

3.10 Recovery to a Dedicated Antaeus Space Station

Reference 7 documents a conceptual design of a small space station dedicated to planetary sample analysis and quarantine. This space station would be constructed in addition to the planned NASA Space Station. The conceptual design proposed housed a crew of five and consisted of five modules and a solar array. The five modules included a laboratory module, a habitation module, a power module, a logistics module, and a docking module. The crew was proposed to consist of an astronaut/engineer, a medical doctor, a geobiologist, a biochemist, and a general biologist.

Reference 7 also provided a cost estimate. This figure was revised and updated based on recent Space Station studies and a new median cost of \$6,104 million was estimated. This option is without a doubt the safest, biologically, of all the options. However, the price paid for this additional safety seems unreasonably high.

4.0 Cost Estimates of the Planetary Sample Handling Options

Table 1 summarizes the cost estimates that are explained in detail in this section. Table 2 gives some idea of where the numbers come from and how they relate to each other. Figure 11 plots cost and risk versus option. These cost and risk estimates are first order numbers only, originally intended only to help choose one or two options for further study.

The cost estimates relate only to the retrieval and handling options at the end of a sample return mission. To design a minimum cost mission, the effect of these options on the overall mission cost must also be determined.

4.1 Common Cost Elements

Except as noted, each of the ten (10) options have elements of work which tend to be common. Cost of these elements should also tend to be similar. Treatment of these elements as a common baseline, with any variation stated, provides a rational basis for comparison. These more or less common cost elements have been identified below. The costs of the Planetary Sample Receiving Laboratory, the Transport and Handling Container, and ground transport are not included in the later individual cost estimates for each option because they are more or less common to all or because their cost is not a large part of the final numbers.

4.1.1 Planetary Sample Receiving Laboratory (PSRL)

The use of ground laboratory facilities for some portion of the total scientific study of the returned samples appears to be a viable requirement applicable to each option. There are two possible cases where the ground laboratory might not be used. One such case would be the availability of a complete Space Station-type facility which could do all envisioned short and/or long-term processing. The other is the case where organisms found in the sample during on-orbit examination would rule against its immediate transfer to Earth. The first exception applies only in the case of a dedicated orbital facility capable of a longer term (months) of processing time.

Options in which there is extensive study of the sample on-orbit might also reduce the requirements on the ground facility, thereby reducing its cost. A reasonable cost for a complete facility on the ground to handle the most dangerous terrestrial organisms now appears to be on the order of 10 to 30 million dollars. This amount includes only the equipment needed to deal with biological risks and does not include other special equipment such a lab might require for other studies. In any case, this number is small relative to the total costs for all the options except direct entry (Option No. 1). For this reason, cost reductions in the ground facility that might occur as a result of on-orbit

Table 1, Cost Estimates by Option

OPTION	RANGE				MEDIAN		RISK	
1	\$	5.2 M	-	9.8 M	\$	7.5 M	1.67	x 10 ⁻⁶
2	\$	150 M	-	173 M	\$162	M	1	x 10 ⁻⁸
3	\$	167 M	-	193 M	\$180	M	< 1	x 10 ⁻⁸
4	\$	302 M	-	714 M	\$508	M	"	"
5	\$	316 M	-	749 M	\$533	M	"	"
6	\$	316 M	-	927 M	\$621	M	"	"
7	\$	605 M	-	1,040 M	\$822	M	"	"
8	\$1,863	M	-	2,456 M	\$2,160	M	"	"
9	\$1,863	M	-	2,456 M	\$2,160	M	"	"
10	\$5,101	M	-	7,107 M	\$6,104	M	"	"

NOTES:

1. Cost of return vehicle/container not included above - applies to all options.
2. Cost of Receiving Lab (\$7M) not included - applies to all options.
3. Share of station costs not charged.
4. All risks are rough order of magnitude except for Option 1.

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Table 2, Cost Estimate Breakdown

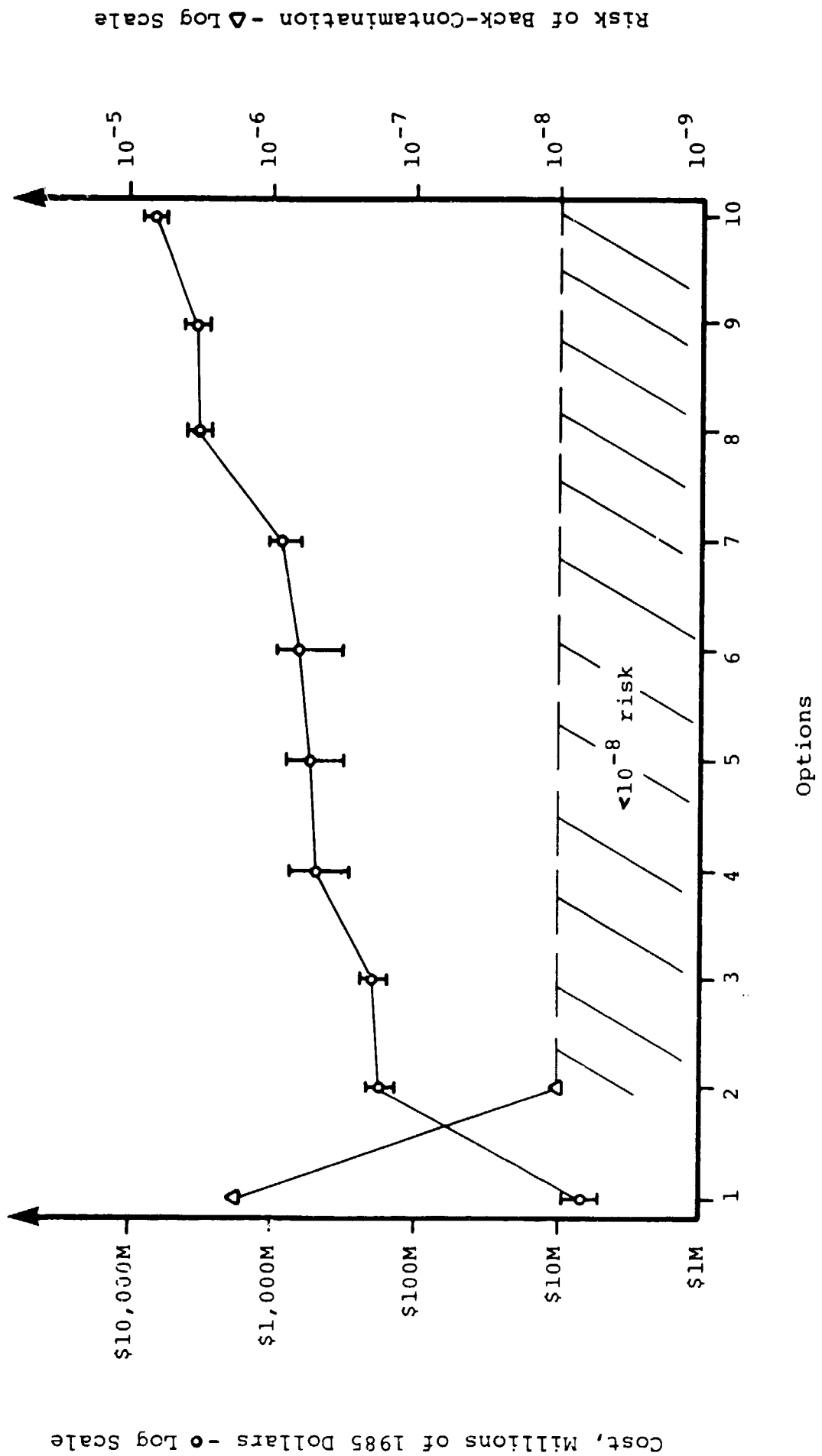
(all numbers are millions of 1985 \$ unless otherwise noted)

Option	1		2		3		4		5	
	High	Low	High	Low	High	Low	High	Low	High	Low
# Shuttle Flights	0.0	0.0	1	1	1	1	2	1	2	1
Shuttle/STS Cost	0.0	0.0	127	113	127	113	254	113	254	113
General other, EVA/OMV/Aircraft	6.7	2.8	6	2	11	6	6	3	6	3
Hardware DDT&E	1.5	1.5	0	0	0	0	250	100	275	110
Subtotal w/o contingency	8.2	4.3	133	115	138	119	510	216	535	226
% Contingency	20.0	20.0	30	30	40	40	40	40	40	40
Contingency Cost	1.6	0.9	40	34	55	48	204	86	214	90
Totals	9.8	5.2	173	149	193	167	714	302	749	316
Median (ave. of high and low)	7.5		161		180		508		533	
% of Tot. that is STS	0.0	0.0	73	76	66	68	36	37	34	36

Option	6		7		8		9		10	
	High	Low	High	Low	High	Low	High	Low	High	Low
# Shuttle Flights	3	1	3	2	4	3	4	3	8	6
Shuttle/STS Cost	381	113	381	226	508	339	508	339	1,016	678
General other, EVA/OMV/Aircraft	6	3	12	6	6	3	6	3	1,584	808
Hardware DDT&E	275	110	350	200	1,240	989	1,240	989	4,506	3,615
Subtotal w/o contingency	662	226	743	432	1,754	1,331	1,754	1,331	7,106	5,101
% Contingency	40	40	40	40	40	40	40	40	0	0
Contingency Cost	265	90	297	173	702	532	702	532	0	0
Totals	927	316	1,040	605	2,456	1,863	2,456	1,863	7,106	5,101
Median (ave. of high and low)	622		823		2,160		2,160		6,104	
% of Tot. that is STS	41	36	37	37	21	18	21	18	14	13

(Contingency is incl.
in other numbers)

Figure 11, Cost and Risk Versus Option



work were not pursued in this first order level study. A single estimate that is generally applicable to all the options was produced.

Although several variants can be visualized, this study is based upon the use of a facility on the order of the Center for Disease Control (CDC) facility in Atlanta. The experience with relatable kinds of investigations should provide a base for both facilities and procedures upon which to estimate cost. Thus, the cost estimate for this study is based (roughly) upon information obtained from CDC.

Assume a dedicated building, or portion thereof, of 1,000-2,000 square feet of total space. Cost, even with the use of prefabricated/factory building shells, is estimated to be two to three times more than conventional use buildings in order to provide leak-proof (both in and out air flow) properties, airlocks, and emergency utility supply. CDC personnel estimated the cost for their latest facility (to be constructed shortly) at \$700 to \$1,000 per square foot with two square feet of support space required for every square foot of lab. Equipment can be drawn from specialized laboratory sources with a modest percentage of the required equipment being special items. The estimated special-purpose one-time use facility and equipment erection and installation cost ranges from just under \$1 million (M) to almost \$6M in 1985\$. The high side of the mid-range value should be used if a single number is needed--about \$4M. (As a check, we can assume that 25 percent of a \$20M --or \$5M--planned facility would be ample for the MSR work.)

There are a number of "level 4" facilities in existence that might be rented. In the U.S., the CDC in Atlanta will probably have two, and the military will have several (Ft. Detrich, Dougway Proving Grounds). Other facilities exist in Europe, Japan, South Africa, and Australia. Australia is reported to have the most expensive facility ever built, the National Animal Health Lab in Geelong. It is used for veterinary work and is reported to have cost around \$500 million U.S. The new CDC facility to be built in Atlanta will cost more than an order of magnitude less than this.

The Europeans are said to be using large plastic cabinets built by Vickers in London instead of large labs in many cases. This approach deserves more investigation.

The manpower estimate has been projected at one year's total effort since training and simulation as well as sample study is appropriate. One year's operating cost is estimated to range from \$6.6M to \$10.15M in 1985\$ with personnel costs being the dominant share. The estimates include both direct and indirect costs.

In summary, a dedicated facility is estimated to range from \$7.6M to \$16.1M in 1985\$ to build and operate for one year. If a single number within the range is used, \$11.6M is suggested. Land value and access roadways are not included, and no requirement for food service or housing have been incorporated.

4.1.2 Transport and Handling Container

Return to an Earth laboratory from the point of in-space transfer requires a container having the required properties to protect the sample and those who come in contact with the hardware; and to allow handling by winch, hoist, fork-lift and transfer devices. The container should facilitate transport by the Orbiter, aircraft, rail, or truck, and in some cases, an OTV/OMV-type vehicle.

It is also possible that the transport and handling container could be the same as that used on the return from Mars leg, or some other small container that would return only the sample in the Orbiter mid-deck. If this proves to be the case, significant cost reductions for some options (a dedicated or partially dedicated orbiter flight might be avoided) would result, but the biological risk might also be significantly increased. This also assumes that the spacecraft returning the sample would be left on-orbit, allowed to re-enter, or docked to the Space Station. A detailed study of the difficulty of loading and sealing the original sample container and of keeping the returning spacecraft uncontaminated is required.

In order to be conservative with respect to biological risk, a large transport and handling container, capable of enclosing the entire spacecraft or some significant fraction of it, as well as the sample itself was assumed. It is also assumed that a tailored design would be used, and that whatever environmental control is required would be part of a self contained unit. A "best guess" estimate using the Airborne Support Equipment (ASE) category was used.

The minimum number of deliverable units is one for all options except option 1. The maximum number is four, three for the three air-snatch aircraft plus one spare.

The cost of the development, production and support is estimated to range from \$1.70M to \$2.96M. This cost is based on a relatively simple article. Interface with the Shuttle could range to \$4.6M.

4.1.3 Transport from Pickup to Lab

Transport from the pickup point in space is based on the use of the Shuttle for all options except direct entry. Transport by Shuttle costs are shown in the Support Cost section (4.1.4) and are

based on the number of flights and whether an OTV is used. The common cost element discussed here is the air, surface, or combination transport from a landing point to the laboratory. Landing points are presumed to be a mid-Pacific air base for direct entry, and either KSC or EAFB for options using the Orbiter. Surface transport is feasible, however, the time required could compromise the protection and conditioning system required for the "smart" container, and perhaps increase the risk of accident during transport. For these reasons, the use of air transport is considered as the prime method and is reflected in the cost estimates. The transport and handling container can easily be transported by C130 aircraft. Section 7 describes a concept for the transport and handling container. Civil C130 costs are baselined, even though DOD or NASA aircraft may be used, since fund transfer amounts are not available.

Cost estimates (based on wet lease with crew) plus factored extras for ground support are:

\$18-20 K for direct entry
\$11-13 K for options landing at Edwards Air Force Base
\$2.7-3.4 K for the Kennedy Space Center landing site

These costs are not large enough to make any difference in the overall comparisons.

4.1.4 National Space Transportation System (NSTS) Support Costs

Transport to and from orbit to support sample retrieval requires the use of the Shuttle/NSTS for all options but direct entry. The variables between the other options consist primarily of the number of flights required and the "special" things done to facilitate the sample return operation. Table 3 shows the number of equivalent flights and the additional demands on the NSTS as well as some other demands. Two accounting considerations are involved:

1. Who pays for NSTS support? It is assumed that NASA pays for the overall cost no matter where the account line item is placed. Thus, NSTS utilization cost is shown as a part of the total but has been isolated to breakout separately as needed.
2. What is the cost/flight? The price per flight to civilian customers is almost firm at \$86M in 1985\$ (74.1 in 1982\$). This subsidized price is at least 30 percent less than the total cost when a share of the total expenditures which directly support NSTS are included. For this estimate, an average cost to NASA of \$120M per flight has been used. This value included an allowance for "special" tasks and equipment required to use the NSTS for sample return. Note: Space Station or ancillary OTV-type vehicles are not included in this section.

Table 3, NSTS and Other Requirements

Option	1	2	3	4	5	6	7	8	9	10
A Shuttle	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
B No. of Flights	None	1	1	1-2	1-2	1-3	2-3	3-4	3-4	6-8
C EVA	No	No	Optional	No	No	No	Yes	Yes	Yes	Yes
D RMS	No	Yes	Optional	Not Specific	Not Specific	Not Specific	Not Specific	Not Specific	Not Specific	Not Specific
E OTV	No	No	No	No	No	No	No	No	No	Yes
F OMV	No	Optional	Yes	Yes	Yes	Yes	Yes	Not Specific	Not Specific	Yes
G Space Station	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
H Complete Module	No	No	No	No	No	No	Yes	Yes	Yes	Yes
I Portion of Module	No	No	No	Yes	Yes	Yes	No	No	No	No
J Antaeus Space Station	No	No	No	No	No	No	No	No	No	Yes
K Special Trans. Container	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
L Automated Handling*	Not Specific	Not Specific	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
M Glove Box in Orbit	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N Sterilize in Orbit	No	No	No	No	No	Yes	Optional	Yes	Yes	Yes
O Quarantine of Crew	Optional	No	No	No	No	Yes	Not Specific	Not Specific	Yes	Yes
P CDC or Equal	Yes	Yes	Yes	Yes	Yes	Yes	Optional	Optional	No	No

* Some degree of automated handling of the sample container desirable in all cases.

4.2 Direct Entry (Option 1)

Assumptions:

1. The sample, its container, and subsystems will be transported from the planetary surface to the Earth in a suitable re-entry vehicle.
2. The vehicle will be capable of reaching a designated point in the atmosphere while decelerating to an acceptable sink rate enabling capture by air-breathing aircraft.
3. Transport aircraft, as typified by the C-130 series, can be considered as representative for cost model purposes.
4. Modifications will include capture subsystem, winch, remote (automated) system for placement and tie-down of vehicle in the cargo hold.
5. The sample, still in its container, will be transported directly to the CDC (or similar facility) by air transport. Costs following landing, being approximately common to all options, are not included in this estimate. The cost of the transport and handling container is also not included.
6. Three configured aircraft will be used to assure availability and to allow more than one pass at the descending payload. Three crews, including support and liaison, of 11 people each will be required.
7. Capture will be done within aircraft radius of Hickam Field, Hawaii. Refueling may be required.
8. Support vehicles might include tracking, command, and control aircraft, helicopter or ships for (emergency) retrieval on the surface, training and logistics. Costs for these items were not estimated and may be significant.
9. Although portions of the re-entry vehicle may be jettisoned during descent, the baseline is to capture and reel in all but expended items.
10. The cost estimate is based on the use of DOD vehicles, crews and support as the primary recovery force.

Direct Entry Worksheet (all costs in millions of 1985 dollars
unless otherwise indicated)

Item	High	Low
1. 3 HC-130E aircraft assigned from DOD. 6 months training and preparation. 6 to 12 flight hours/week/aircraft 468 to 936 flight hours tot. req. \$3,825 per hour incl. crew and equipment.	3.6	1.8
2. Modifications to aircraft/equipment \$200K per aircraft.	0.6	0.6
3. \$600K for the modification of, and \$300K for the maintenance of other special equipment.	0.9	0.9
4. Direct support for 6 months subtotal.	5.1	3.3
5. Allowance for indirect support, NASA technicians, other @ 30% to 60% of direct support.	3.1	1.0
6. Total less contingency.	8.2	4.3
7. Contingency --20% of total (since air snatch is done commonly, the contingency is not large).	1.6	.9
8. Total with contingency.	9.8	5.2
9. Median (average of high and low).	7.5	

4.3 Shuttle Recovery (Option 2)

Assumptions:

1. The return vehicle containing the sample is (automatically) positioned in Earth orbit within reach of the NSTS Orbiter.
2. The sample is placed in a transport and handling container in the payload bay with the remote manipulator system (RMS). Use of the OMV is considered to be required in the high cost model.
3. Upon landing, the container is removed from the Orbiter, and placed in transport aircraft for movement to the CDC or other site. Costs after landing, being approximately common to all options, are not included.

Shuttle Recovery Worksheet (all costs in millions of 1985 dollars unless otherwise indicated)

Item	High	Low
1. Basic cost of NSTS dedicated mission \$120M \pm 7M.	127	113
2. Special provisions for container handling.	2	1
3. Augmented ground handling and transport.	1	0.5
4. Optional use of OMV. This assumes the OMV can do the retrieval. A specially configured OTV may be required. See 3.2 discussion.	3	0
5. Direct cost subtotal.	133	115
6. Contingency --30%.	40	35
7. Total with contingency.	173	150
8. Median (average of high and low) Note: Transport & Handling Container cost not included.	162	

4.4 Recovery to the Space Station Structure for Pick-up (Option 3)

Assumptions:

1. One equivalent dedicated NSTS mission will be required to bring up the special hardware and crew to install it and return the container to Earth.

A transport and handling container to return the entire spacecraft could be very compact, taking up only 1 or 1.5 meters of the 18.3 meters of length (60 ft) available in the payload bay. Due to the Shuttle policy of charging on the basis of fraction of payload bay length or fraction of payload mass, whichever is greatest, the mass of this payload will determine the charge.

If the container was designed for great strength with crash-worthiness in mind, with perhaps a 5 cm (2 inch) steel wall, it might weigh in the range of 7 to 10 metric tons including airborne support equipment, refrigeration, and other equipment. The 5 cm steel wall will be the great majority of the mass. See section 7.0. Metals other than steel (titanium?) may be better selections.

The OMV is assumed to be based at the Space Station. A 3 metric ton load of fuel must also be carried up for it. In all a total mass of 10 to 14 metric tons going up might be required and 7 to 8 metric tons going down. If the OMV is ground based, another 2 metric tons up and down would be required.

The current Shuttle payload (up) to 230 nautical miles (nm) is 19.1 metric tons or 42,000 lbs. The Space Station altitude is uncertain at present, but numbers such as 220 and 270 nm have been discussed. The payload (up) to 270 nm is in the range of 17.7 metric tons.

The payload down is around 14.5 metric tons or 32,000 lbs.

The transport and handling container, associated equipment, and OMV fuel could, therefore be in the range of 10 to 16 metric tons out of a possible maximum payload of 18 to 20 metric tons up. One equivalent dedicated Shuttle flight is therefore a reasonable assumption.

2. The variation on this option of taking the transport and handling container to the sample instead of the other way around will be more expensive (especially if the container is massive) and is not considered here. The cost of the transport and handling container and ground costs approximately common to all options are not included in these estimates.

Recovery to Space Station Structure for Pick-up Worksheet
 (all costs in millions of 1985 dollars unless otherwise indicated)

	Item	High	Low
1.	One equivalent Shuttle flight (up & down) \$120M \pm 7M.	127	113
2.	Special Provisions for container handling.	3	2
3.	Augmented ground handling/transport.	2	1
4.	EVA/OMV use.	6	3
5.	Direct cost subtotal.	138	119
6.	Contingency --40% of subtotal.	55	48
7.	Total with contingency.	193	167
8.	Median (average of high and low).	180	

4.5 Recovery to the Space Station for Repackaging (Option 4)

Assumptions:

1. The modifications to the Life Sciences Module airlock door and structure, including hardware, EVA, etc. plus OMV fuel could result in no more than one dedicated Shuttle mission up to deliver hardware and people.

In the best case, an EVA crewman might do all the work, and there would be nothing to haul up or down in the payload bay. In the worst case the complete Life Sciences Module might have to be brought down (to the Earth's surface) for modification and then taken up, taking at least one full payload bay up and down and probably two dedicated missions.

If this option is seriously considered, the ease of modifying the life sciences module airlock should perhaps be examined now, before it is designed and launched.

2. The cost for the sample to ride down in the mid-deck is not included. The biological risk may increase significantly if this is done and in some opinions a dedicated flight would be required.
3. The returned spacecraft (less sample) can be stored forever without cost on the Space Station structure or de-orbited with other refuse at some time for no cost.

Recovery to Space Station for Repackaging Worksheet

(all costs in millions of 1985 dollars unless otherwise indicated)

Item	High	Low
1. One or two equivalent Shuttle flights (up & down) \$120M \pm 7M.	254	113
2. Modifications to airlock door, other structure, etc.	250	100
3. EVA/OMV use.	6	3
4. Direct cost subtotal.	510	216
5. Contingency--40% of subtotal.	204	86
6. Total with contingency.	714	302
7. Median (average of high and low).	508	

4.6 Recovery to the Space Station with Minimal Analysis (Option 5)

Assumptions:

1. The modifications to the Life Sciences Module airlock door and structure, including hardware, EVA, etc and the minimal analysis equipment to be placed inside the Life Sciences Module, plus OMV fuel, will result in no more than one dedicated Shuttle mission up to deliver hardware and people.

In the best case, an EVA crewman might remove the sample from the spacecraft in the airlock or on the Station structure and bring it into the Life Sciences Module via the normal airlock. Only the analysis equipment and perhaps a disposable "oversuit" and the people to do the analysis might be required to go up. Depending on the analysis equipment, this might all fit in the mid-deck.

In the worst case the complete life sciences module might have to be brought down (to the Earth's surface) for modification and then taken up, taking at least one full payload bay up and down and probably two dedicated missions.

2. The cost for the sample to ride down in the mid-deck is not included. There may be considerable biological risk with this plan and in some opinions, a dedicated flight would be required.
3. The returned spacecraft (less sample) can be stored forever without cost on the Space Station structure or de-orbited with other refuse at some time for no cost.

Recovery to Space Station with Minimal Analysis Worksheet (all costs in millions of 1985 dollars unless otherwise indicated)

Item	High	Low
1. One or two equivalent Shuttle flights (up & down) \$120M \pm 7M.	254	113
2. Modifications to airlock door, and interior of Life Sciences Module.	275	110
3. EVA/OMV use.	6	3
4. Direct cost subtotal.	535	226
5. Contingency--40% of subtotal.	214	90
6. Total with contingency.	749	316
7. Median (average of high and low).	533	

4.7 Recovery to the Space Station with a Small Sample Sterilized and Sent to Earth (Option 6)

Assumptions:

1. The modifications to the Life Sciences Module airlock door and structure, including hardware, EVA, etc and the sterilization equipment to be placed inside the Life Sciences Module, plus OMV fuel, will result in no more than one dedicated Shuttle mission up to deliver hardware and people. In the event that some evidence of life is found, or there is no confidence in the Earth-based analysis of the sterilized sample, a second dedicated mission, with analysis equipment, would be required. Two dedicated missions are therefore budgeted, with the second being optional.

In the best case, an EVA crewman might remove the sample from the spacecraft in the airlock or on the Station structure and bring it into the Life Sciences Module via the normal airlock. Only the sterilization equipment and perhaps a disposable "oversuit" and the people to do the sterilization might be required to go up. Depending on the sterilization equipment, this might all fit in the mid-deck. If no evidence of life is found and there is some confidence in this finding, the remaining sample can then be returned without extensive precautions in the mid-deck. Thus no payload bay space is required.

In the worst case the complete Life Sciences Module might have to be brought down (to the Earth's surface) for modification in preparation for the sterilization of a small sample and storage of the large sample, and then taken up again, taking at least one full payload bay up and down and probably two dedicated missions. If life is found additional analysis equipment and people might then be brought up in one or more dedicated missions. As many as three or more dedicated missions might therefore be required.

Both the "best" and "worst" cases described above are feasible in an engineering sense. The biological risk of each must be compared, which is beyond the scope of this study.

2. The cost for the sample to ride down in the mid-deck is not included.
3. The returned spacecraft (less sample) can be stored forever without cost on the Space Station structure or de-orbited with other refuse at some time for no cost.

4. The impact (cost) of Space Station crew quarantine is assumed to be zero.
5. The cost for storage and refrigeration of the bulk of the sample on-orbit is not included.

Recovery to Space Station with a Small Sample Sterilized and Sent to Earth Worksheet (all costs in millions of 1985 dollars unless otherwise indicated)

	Item	High	Low
1.	One to three equivalent Shuttle flights, \$120M \pm 7M each.	381	113
2.	Modifications to airlock door, and interior of Life Sciences Module, including sterilizer.	275	110
3.	EVA/OMV use.	6	3
4.	Direct cost subtotal.	662	226
5.	Contingency--40% of subtotal.	265	90
6.	Total with contingency.	927	316
7.	Median (average of high and low).	621	

4.8 Recovery to a Separated Quarantine Module (Option 7)

Assumptions:

1. The Quarantine Module and all its associated equipment, consumables, crew, structural attachments, etc, and the OMV or OMV fuel can fit in two dedicated Shuttle missions up. The module will require one mission all by itself. The transport and handling container might require another half mission up and down (based on weight). The total STS requirement is therefore assumed to be two to three dedicated missions. The Quarantine Module is assumed to stay with the Station forever once it is put in place.
2. The Quarantine Module itself is assumed to cost between \$200 and \$350 million dollars, all costs included. The capabilities of this module are assumed to be more than could be brought up and placed in the Life Sciences Module, but less than would be found in an Antaeus Lab Module, which would be a highly developed zero-g laboratory, capable of performing the protocol specified in reference 7.
3. Since the Quarantine Module is separated from the rest of the Station, considerable EVA and OMV activity will be required.

Recovery to a Separated Quarantine Module Worksheet (all costs in millions of 1985 dollars unless otherwise indicated)

	Item	High	Low
1.	Two to three dedicated Shuttle flights @ \$120M \pm 7M.	381	226
2.	Design, development, test, engineering, and production of one Quarantine Module.	350	200
3.	EVA/OMV use.	12	6
4.	Direct cost subtotal.	743	432
5.	Contingency--40% of subtotal.	297	173
6.	Total with contingency.	1,040	605
7.	Median (average of high and low).	822	

4.9 Recovery to the Space Station Antaeus Lab Module (Option 8)

Assumptions:

1. Two to three Shuttle flights are required for the same reasons noted in the previous option, except with the Antaeus Lab Module replacing the Quarantine Module. An additional dedicated Shuttle flight may be required to bring up more consumables and equipment in support of extended analysis. The total assumed is, therefore, three to four flights.
2. A sophisticated Antaeus Lab Module (from Ref. 7) is added to the Station in lieu of the Life Sciences Module.
3. Analysis on-orbit may require long periods of time.
4. Other Station work may be impacted.
5. Module development, manufacture, assembly, checkout, etc., can be treated as a share of the Space Station.

Recovery to Space Station Antaeus Lab Module Worksheet (all costs in millions of 1985 dollars unless otherwise indicated)

Item	High	Low
1. Three to four dedicated Shuttle flights @ \$120M \pm 7M.	508	339
2. Antaeus Module:		
Design, Development, Test, and Eng. (54%).	670	518
Production (21% of Module total).	260	231
Operations (25% of Module total).	310	240
3. EVA/OMV use.	6	3
4. Direct cost subtotal.	1,754	1,331
5. Contingency--40% of subtotal.	705	532
6. Total with contingency.	2,456	1,863
7. Median (average of high and low).	2,160	

4.10 Recovery to a 1/2 Quarantined Space Station (Option 9)

Assumptions:

This option is essentially the same as the previous option with a different quarantine set-up. The difference between this option and the previous one is within the estimating tolerance, so the cost will be taken as the same: high--\$2,456M, low--\$1,863M, median--\$2,160M. More detailed study may show this option to have a somewhat higher cost.

4.11 Recovery to a Dedicated Antaeus Space Station (Option 10)

Assumptions:

1. Two existing cost estimates were used for estimating by the relationship method.
 - a. The Antaeus space station cost estimate, from reference 7.
 - b. Current estimates for the proposed NASA Space Station.
2. The Antaeus report estimate was normalized to reflect inflation to 1985 dollars and a factor for government support efforts (wrap around) was included. The calculations are shown below.
3. Six to eight dedicated Shuttle missions are assumed to be required to place and service the Antaeus facility for one year.
4. A second estimate was calculated assuming that the dedicated station would be similar to the initial NASA Station. A share of the planned station representing the functions required for Antaeus station operations compared within the range, but to the high end of the estimate shown below.

Dedicated Antaeus Space Station Worksheet (all costs in millions of 1985 dollars unless otherwise indicated)

Item	High	Low
1. Antaeus report cost numbers (1978 dollars)		
Design, development, test, and engineering.	1,186	1,186
Production.	458	458
Operations (1 to 15 years).	1,108	565
2. Antaeus Subtotal (1978 dollars).	2,662	2,209
3. Inflation to 1985 dollars (add 43%).	1,145	950
4. Antaeus Subtotal (1985 dollars).	3,807	3,159
5. NASA wrap around--contractor cost to budget line item (includes APA/contingency) 40% minimum to 60% maximum.	2,284	1,264
6. Antaeus with wraps subtotal.	6,091	4,423
7. Add 6 to 8 Shuttle missions @ \$120M \pm 7M.	1,016	678
8. Antaeus Total.	7,107	5,101
9. Median (average of high and low).	5,104	

5.0 The Thermal Environment in the Vicinity of Earth

Steady state surface temperatures of passive thermal coatings are shown in Tables 4 and 5. Two values of absorptivity (.2 & .1) and an emissivity value of 0.8 were used for the comparison since they are representative of coatings that have been used during other programs. The comparison shown is for three orbits (circular, 12 hr. ellipse, and 24 hr. ellipse) and for two conditions, maximum and minimum view factor to sun, for a cylinder with dimensions that approximate the Earth Return Vehicle (ERV).

Radiated heat from the Earth is the primary source of energy (and temperature increase) for the sample/spacecraft in Earth orbit. In the high elliptical orbits, the sample is far away from Earth for most of the orbit and the "view factor" is small. Figures 12, 13, and 14 relate this "view factor" to time and altitude. The view factor is roughly the fraction of the sky the spacecraft sees that is filled by the Earth. The maximum view factor is one.

As shown in the tables, the surface temperatures range from 237 to 144 degrees Kelvin. For a passively controlled system, two factors determine the significance of the surface temperatures to the condition of the Sample Cannister Assembly (SCA). One is the effectiveness of the intervening insulation, and the other is the time lapse before the sample cannister assembly is removed from the Earth Return Vehicle for conditioning. If "enough" time passes the inner structures will approach the surface temperature. "Enough time" is directly related to the effectiveness of the insulation.

Typically, either active thermal control, heat capacitance or some combination of the two is used to extend allowable times. Active thermal control includes refrigeration and radiators. Heat capacitance includes thermal masses and phase change materials. Another form of active thermal control includes attitude control of the spacecraft or its subsystems such as the radiator. It is believed that all of these methods are being considered in other contractual efforts for the Earth Return Vehicle and will probably achieve design requirements.

A determination of the effectiveness of any approach for this unique activity is beyond the scope of this effort. The purpose and benefit of this work is to show the limits that will occur if passive thermal control is the only approach used and "enough" time lapses. The additional benefit is to compare the influence of the thermal environment for three orbits. The steady state surface temperatures vary inversely with the orbital period. Thus the longer the period the "cooler" the surface, since the spacecraft will be farther from the Earth for longer periods. Trades to determine the effect of compromises for this type of interaction have been the subject of extensive studies during

similar programs. Presumably, this trade will be considered in the thermal study that has been proposed.

This information is presented to help provide some basis for decision making and for inquiring with respect to the approaches proposed for thermal control of the Earth Return Vehicle.

Table 4, Maximum Solar View Factor

	CIRCLE	ELLIPSE	ELLIPSE	CIRCLE	ELLIPSE	ELLIPSE
Perigee, km		7,076	7,076		7,076	7,076
Apogee, km	7,076	46,144	77,405	7,076	46,144	77,405
Period, hours		12	24		12	24
Beta, degrees	28.5	28.5	28.5	28.5	28.5	28.5
Absorptivity	.2	.2	.2	.1	.1	.1
Emissivity	.8	.8	.8	.8	.8	.8
ERV Radius, meters	.3	.3	.3	.3	.3	.3
ERV Length, meters	.92	.92	.92	.92	.92	.92
Solar View Factor	.24	.24	.24	.24	.24	.24
Stefan-Boltz E+8	5.67	5.67	5.67	5.67	5.67	5.67
Albedo	.39	.39	.39	.39	.39	.39
Time Avg.View Factor	.17	8.82E-3	4.28E-3	.17	8.82E-3	4.28E-3
Earth View Factor	.312	.0278	.0132	.312	.0278	.0132
Insolation w/m ²	1,353	1,353	1,353	1,353	1,353	1,353
Earth Radiosity w/m ²	243	243	243	243	243	243
Steady State Temp °K	237	199	197	218	171	167

Table 5, Minimum Solar View Factors

	CIRCLE	ELLIPSE	ELLIPSE	CIRCLE	ELLIPSE	ELLIPSE
Perigee, km		7,076	7,076		7,076	7,076
Apogee, km	7,076	46,144	77,405	7,076	46,144	77,405
Period, hours		12	24		12	24
Beta, degrees	28.5	28.5	28.5	28.5	28.5	28.5
Absorptivity	.2	.2	.2	.1	.1	.1
Emissivity	.8	.8	.8	.8	.8	.8
ERV Radius, meters	.3	.3	.3	.3	.3	.3
ERV Length, meters	.92	.92	.92	.92	.92	.92
Solar View Factor	.12	.12	.12	.12	.12	.12
Stefan-Boltz E+8	5.67	5.67	5.67	5.67	5.67	5.67
Albedo	.39	.39	.39	.39	.39	.39
Time Avg.View Factor	.17	8.82E-3	4.28E-3	.17	8.82E-3	4.28E-3
Earth View Factor	.312	.0278	.0132	.312	.0278	.0132
Insolation w/m ²	1,353	1,353	1,353	1,353	1,353	1,353
Earth Radiosity w/m ²	243	243	243	243	243	243
Steady State Temp °K	223	172	168	209	149	144

Figure 12

ALTITUDE VS VIEW FACTOR

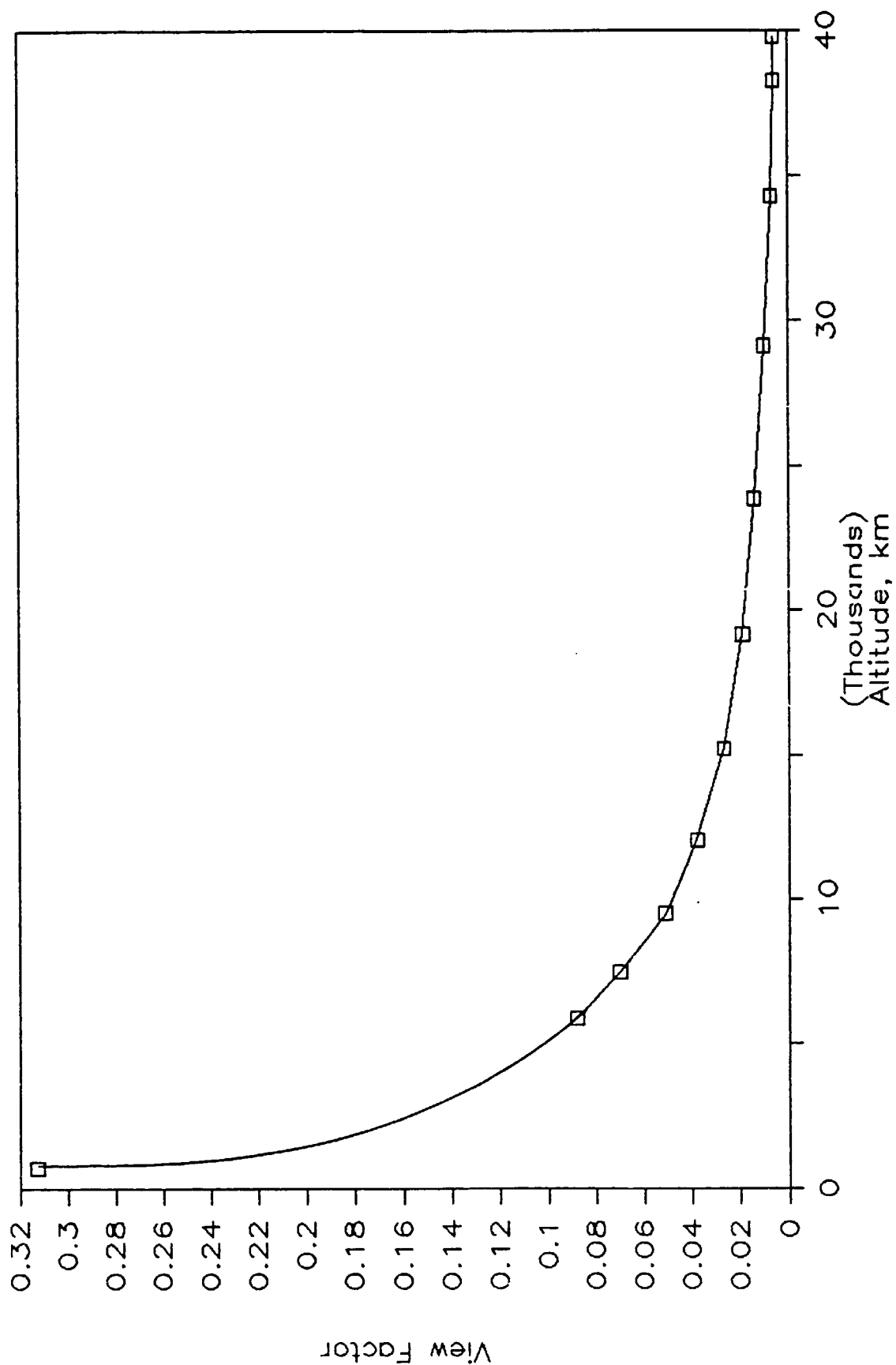


Figure 13

ALTITUDE VS TIME

12 HR - ELLIPTIC ORBIT

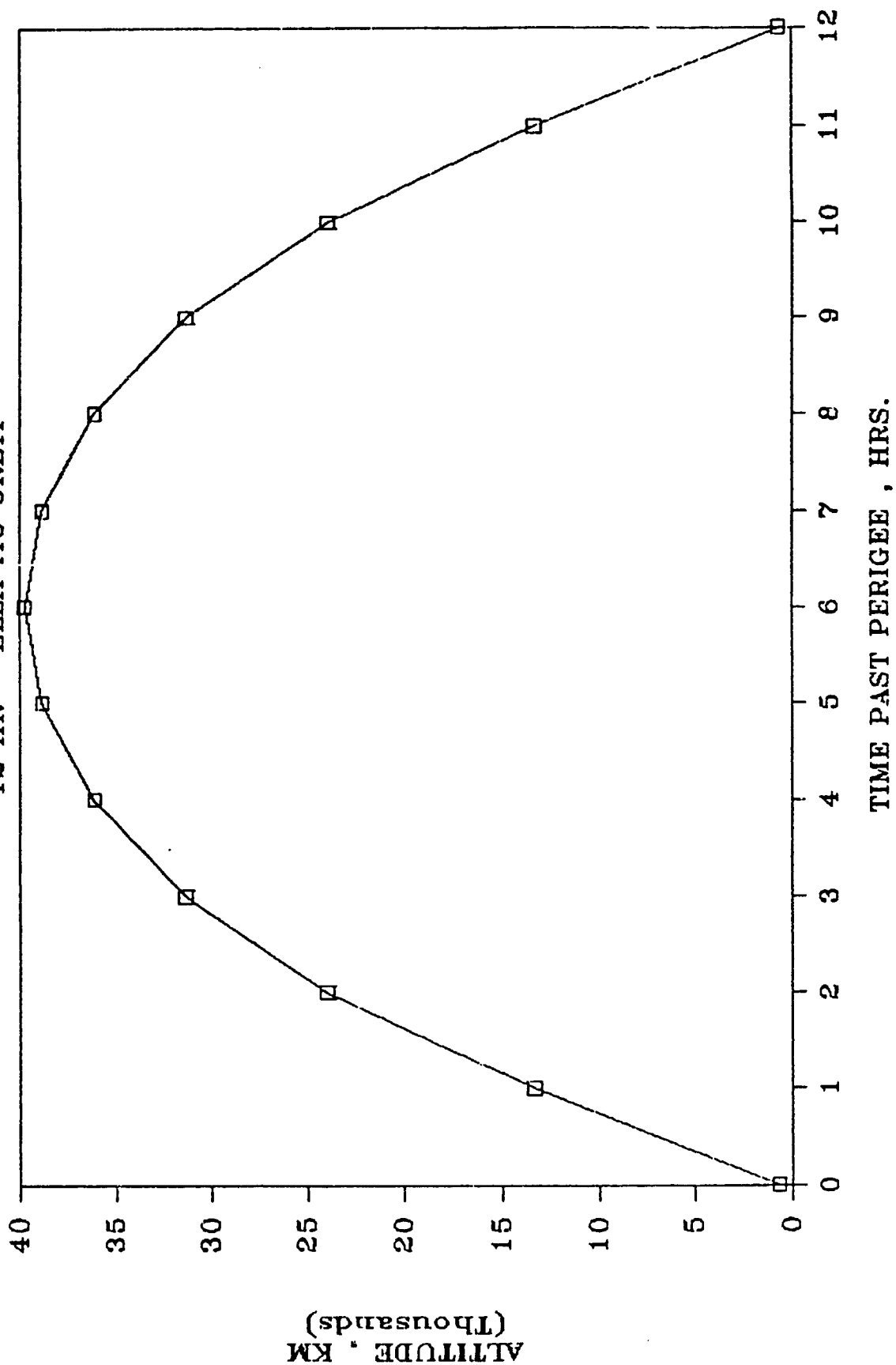
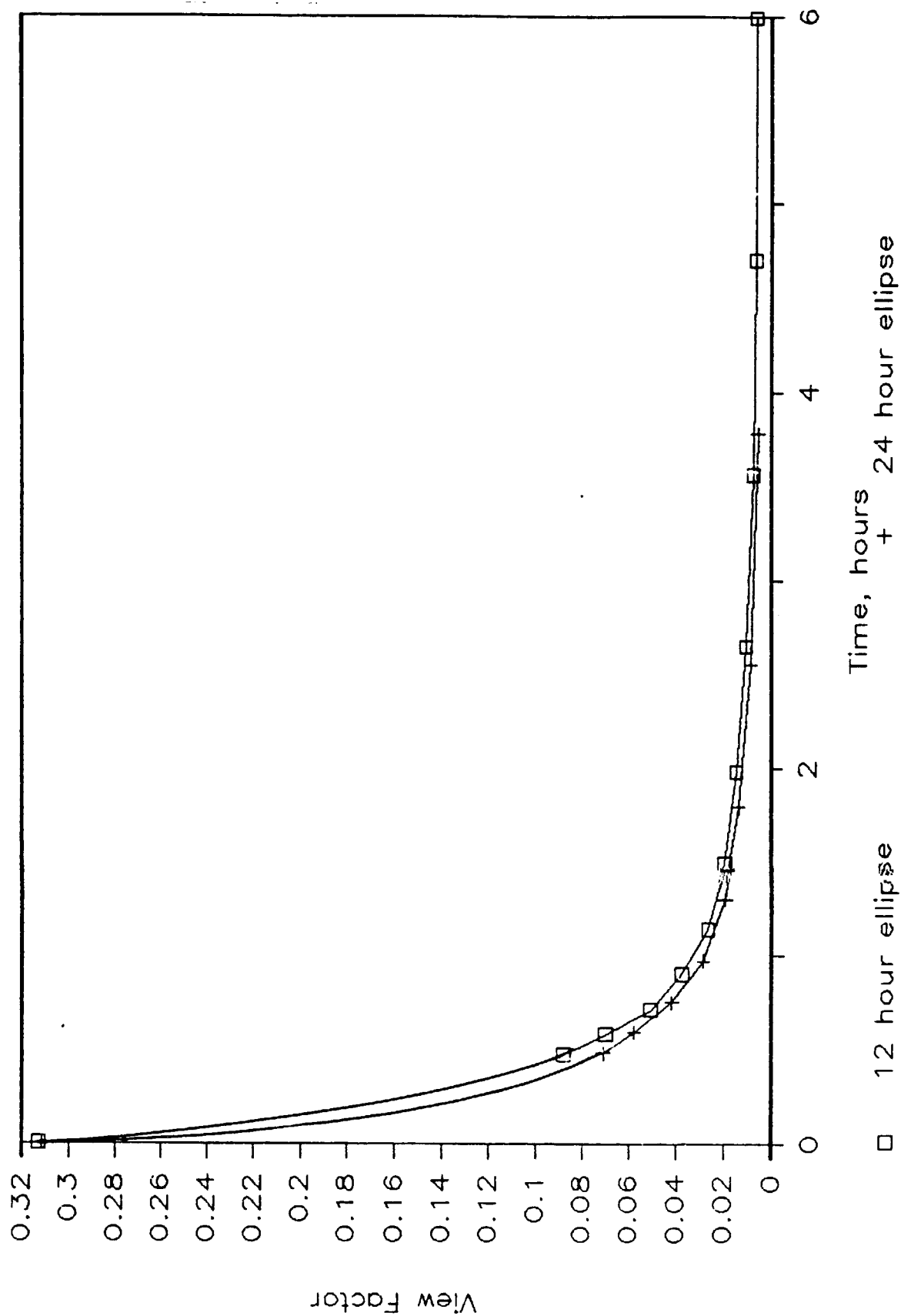


Figure 14

TIME VS. VIEW FACTOR



6.0 Methods for Rapid Recovery of Planetary Samples after Earth Orbit Insertion

6.1 Background

With the exception of the direct entry option in which the returning planetary sample probe makes a direct entry to the Earth's surface a-la-Apollo, all options require a rendezvous with and retrieval of the sample from some Earth orbit. In the second option the retrieval vehicle leaves from and returns to the Shuttle, while in all other options, it leaves from and returns to the Space Station. Otherwise, the retrieval problems are the same.

6.2 Retrieval Vehicles

Two types of retrieval vehicles were considered, an Orbital Maneuvering Vehicle (OMV) or a high energy LO_2/LH_2 stage such as a Centaur.

The OMV is a specialized retrieval vehicle now being developed. It is expected to have an empty weight of -1,856 kg and usable propellant weight of -3,000 kg. The propellant will be storable bipropellant ($\text{N}_2\text{O}_4/\text{MMH}$) with an Isp of 285 sec. This gives the vehicle a delta V capability of 2,700 m/sec empty and 2,010 m/sec with a 1 MT payload.

The Centaur was assumed to have an empty weight of 2,270 kg (5,000 lb) and a fuel capacity in excess of 10 MT. An Isp of 450 sec was assumed for the LO_2/LH_2 propellant.

6.3 Scenarios

Two basic scenarios are being considered. In one, the returning probe, with sample, aerobrakes into a circular or nearly circular low Earth orbit. This scenario should result in a final orbit with perigee of from 200 to 700 km and apogee less than 1,000 km.

In the second scenario, the probe, with sample, uses propulsive braking to enter a high (12 to 24 hr) elliptical orbit. Here perigee altitude is 700 km or less and apogee altitude is 40,000 Km and up (40,000 km for 12 hr. orbit, 70,000 for 24 hr orbit). To bring the probe on down to a low circular orbit would require -2.5 km/sec more delta V from the propulsive system. This would increase the total returned weight by nearly 2.5 times. This is an unacceptable penalty.

In both scenarios, after Earth orbit is achieved, a retrieval vehicle based at the Space Station rendezvous with and captures the sample and returns it to the Space Station. The retrieval vehicle carries containment and/or environmental maintenance facilities on-board.

In both scenarios, minimizing the time between Earth orbit entry and capture by the retrieval vehicle is important because of sample heating in the Earth orbit environment. Comet samples, for example, need to be kept at $\sim 100^{\circ}\text{K}$ to maintain their pristine state. This low temperature can be maintained in interplanetary space but the heat pulse of orbit entry combined with the extra heat flux added by reflection from the Earth may require that active cooling be applied within a time measured in hours rather than days. The purpose of this section is to determine techniques for fast recovery, determine the performance necessary to employ the technique and indicate what sort of time period might reasonably be necessary for the maneuvers.

6.4 Retrieval of an Aerobraked Sample from Low Circular Orbit

Returning the probe to a low circular or nearly circular orbit may be possible using aerobraking, but difficult using all propulsive orbit entry. The cost for fuel for the latter case would be prohibitive, more than doubling the weight of the return vehicle.

With aerobraking the returning probe targets to the plane of the Space Station, on an orbit with perigee in the atmosphere (slightly below 100 km). The probe is guided through the atmosphere phase to emerge with apogee ~ 500 km. This maneuver may take more than one pass. When the desired exit apogee is achieved, the probe coasts to apogee and uses a posigrade propulsive burn to raise perigee up out of the atmosphere (circularize).

The resultant orbit is close to the same orbit as the retrieval vehicle.

6.4.1 Groundrules for the Low Circular Orbit Case

- O The sample enters a 500 x 500 km orbit.
- O The retrieval stage is in a 500 x 500 km orbit pre-positioned to be in the same plane as the incoming sample.
- O No aerobraking is used on the retrieval stage.
- O For fuel calculations, the retrieval stage is assumed to be carrying a 1,000 kg payload out and back.
- O All delta V's include return to the original orbit.
- O The initial orbits cannot be reduced for phasing because of the proximity of the atmosphere.

6.4.2 Maneuver Sequences for the Low Circular Orbit Case

Figure 15 illustrates the maneuver sequence suggested for a fast rendezvous with a target in low circular orbit.

The maneuver sequence starts at Time 1. This is after the target enters the parking orbit and a period of tracking has been used to establish the orbit and position of both the target and the maneuvering vehicle.

At Time 1 the target is some phase angle between zero and 360° ahead of the Maneuvering Vehicle (MV). The MV then boosts up into an ellipse.

At Time 2 the MV has reached apogee and makes a small maneuver to adjust perigee exactly to the target altitude. At this point the target has coasted around past the perigee point.

At Time 3 the MV and the target have reached perigee at the same time. The MV retards into the circular orbit by matching speeds with the target. The total time is between 1 and 2 orbital periods of the target depending on the initial phase angle.

6.4.3 Maneuver Time as a Function of Phase Angle for Low Circular Orbit Case

Figure 16 shows the total time from 1 to 3 as a function of the initial phase angle. Again, phase angle is the angle that the target is ahead of the Maneuvering Vehicle. Time is shown for the quickest time (1 to 2 periods) discussed above, and also for the lower ellipse where the MV goes around the ellipse twice reaching perigee the second time just as the target passes it for the third time (i.e., it takes two orbits of the ellipse for the target to "catch up" rather than one). This is the case marked 2 to 3 periods.

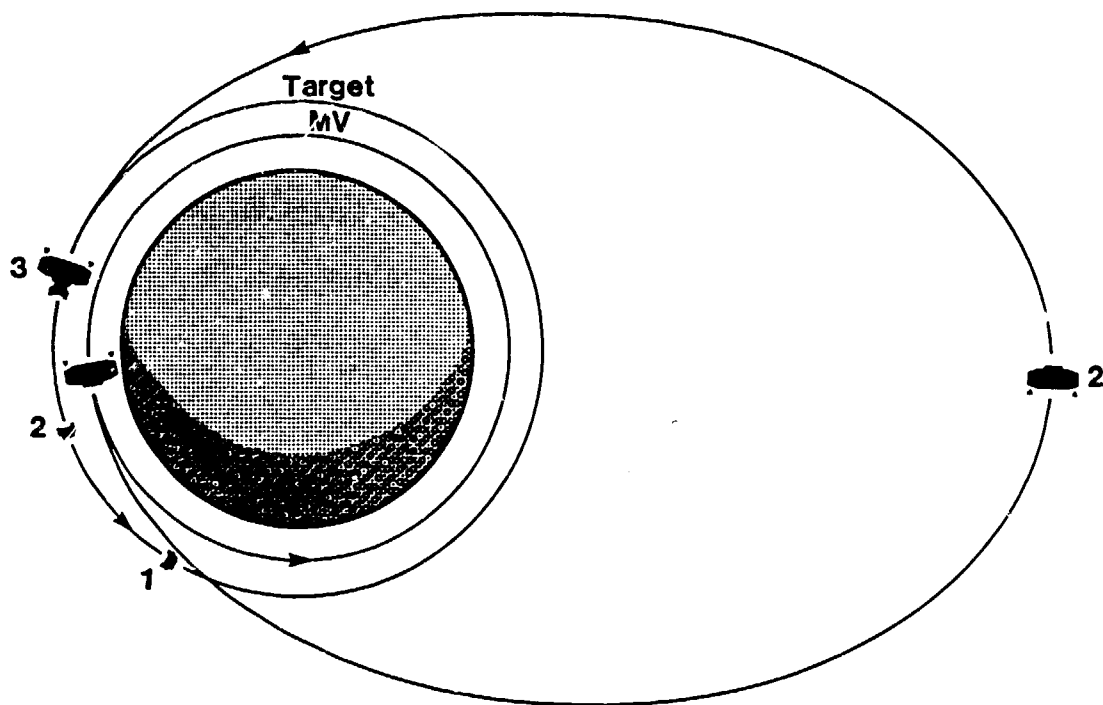
This case is for both vehicles in a 500 km circular orbit. Change in target orbit changes this time but only by the ratio of the new orbit period to the 500 km circular orbit period.

6.4.4 Delta V for Maneuvers

Figure 17 gives the delta V necessary to perform the rendezvous maneuvers, that is to boost into the ellipse and then match speeds by recircularization. Again, this is the case where both MV and target are in 500 km circular orbits. Altering the target orbit altitude by a couple of hundred km would increase the delta V by only about 0.1 km/sec so the results are fairly general for the low circular case.

Figure 15, Low Circular Orbit Maneuver Sequence

Target in Low Circular Orbit
MV= Maneuvering Vehicle



Time-1 MV Boosts to Ellipse
Time-2 MV adjusts perigee to Target altitude
Time-3 MV matches Velocity with Target

Total Time 1 to 3 is between 1 to 2 periods of Target Orbit

Figure 16

MANEUVER TIME CIRCULAR ORBITS

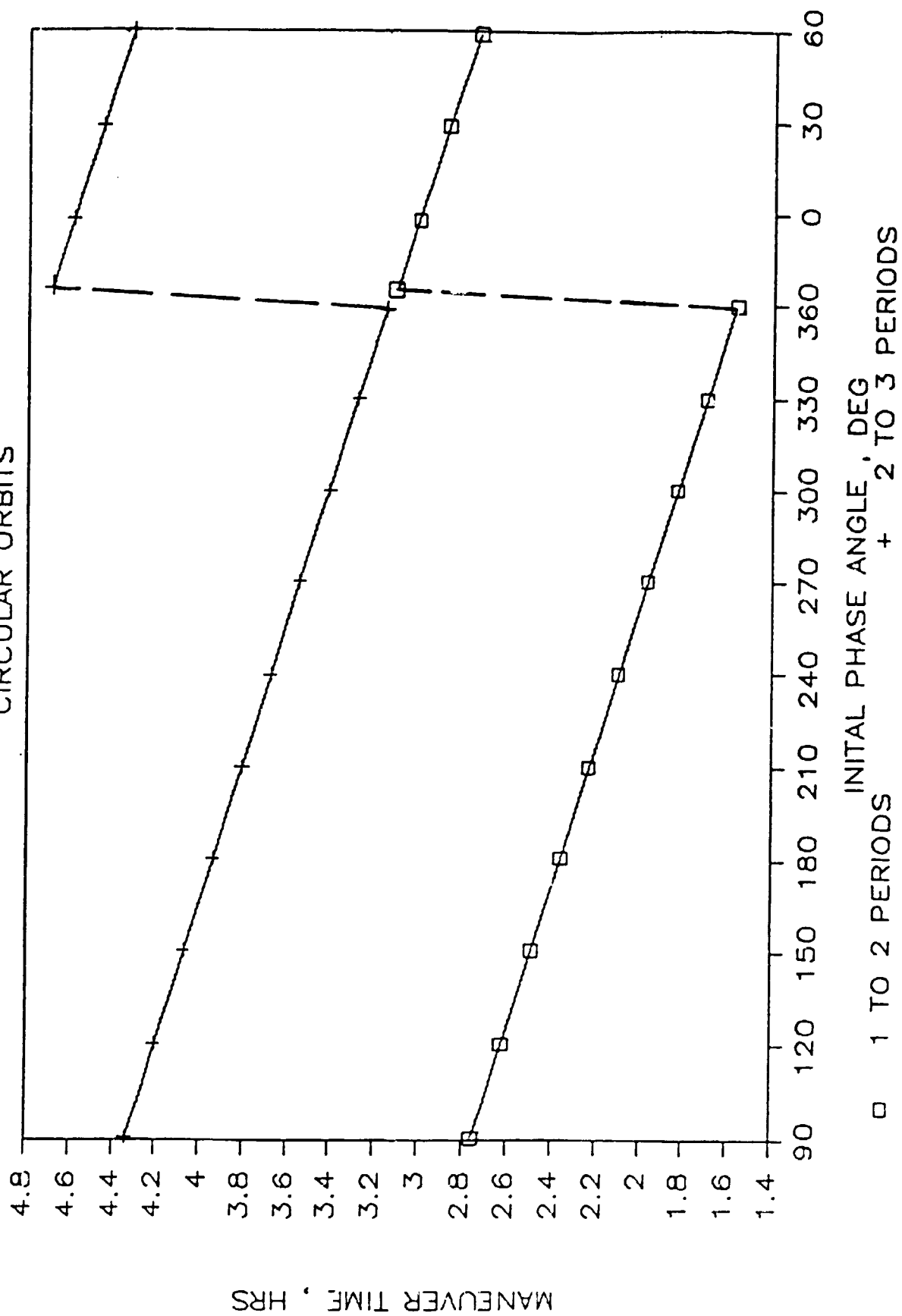
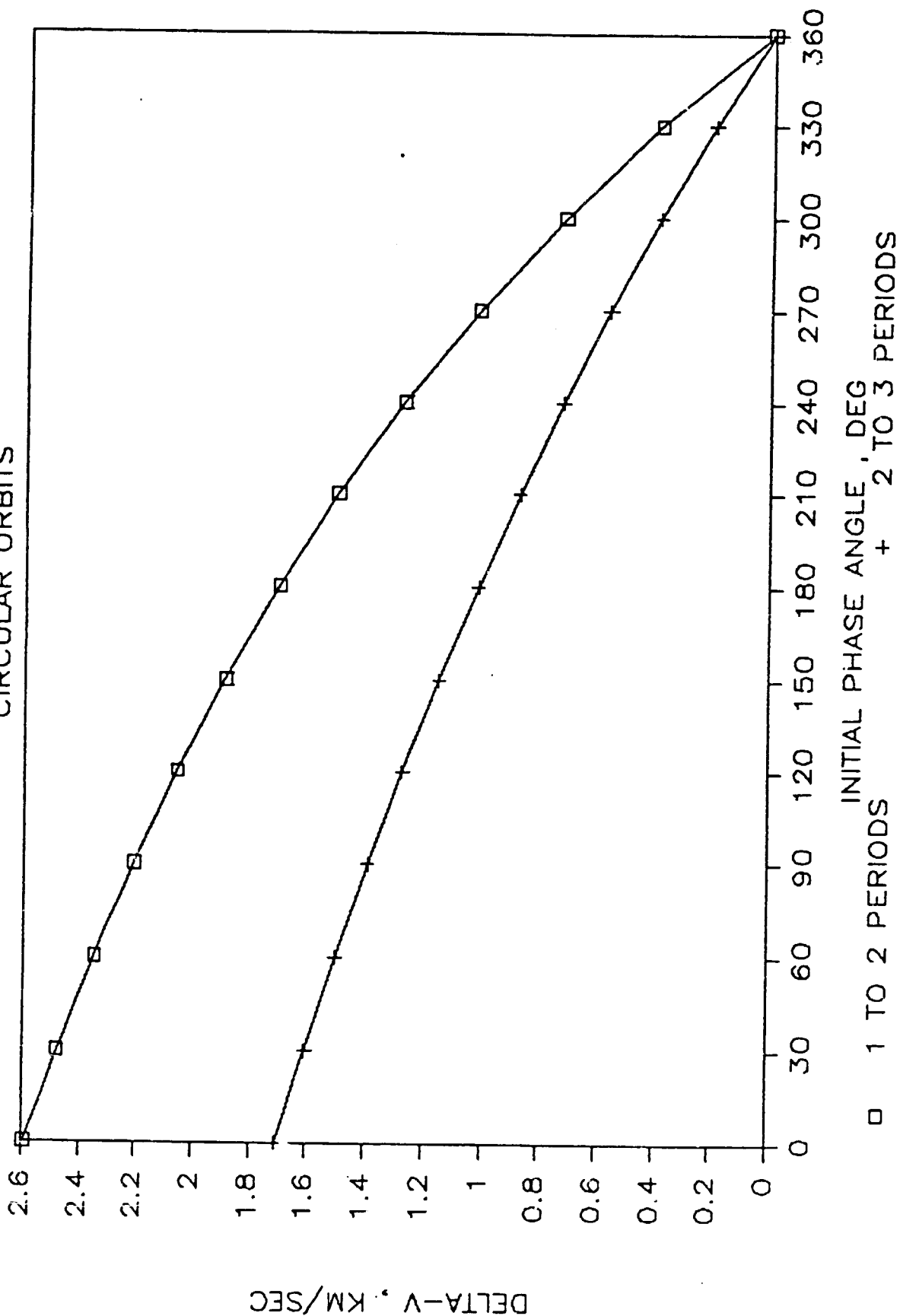


Figure 17

TOTAL DELTA-V CIRCULAR ORBITS



6.4.5 Fuel Required for Low Circular Case

Figure 18 shows the fuel usage required of an OMV to perform the rendezvous carrying a 1 MT payload. The OMV fuel capacity of 3 MT is indicated by the horizontal line. This shows that the low circular orbit retrieval could be performed by an OMV but it requires a full propellant load and even then some control of the initial phase angle may be necessary or else a slightly longer rendezvous time would be needed.

6.4.6 Total Time Required to Rendezvous for Low Circular Case

The total rendezvous time for the low circular orbit case, starting when the final orbit is achieved by the target, is given by:

Total Time = Tracking time + Time to correct out of plane errors + Maneuvering time + Proximity Operations time.

Where Tracking time is the time to determine the state vectors of both bodies. This should be only a fraction of an hour if TDRSS's or Global Positioning Satellites are available.

Time to correct out of plane errors is the time necessary for the MV to shift exactly in plane. This will be less than half of a period or about 0.7 hr.

Maneuvering time is the time shown in the preceding graphs.

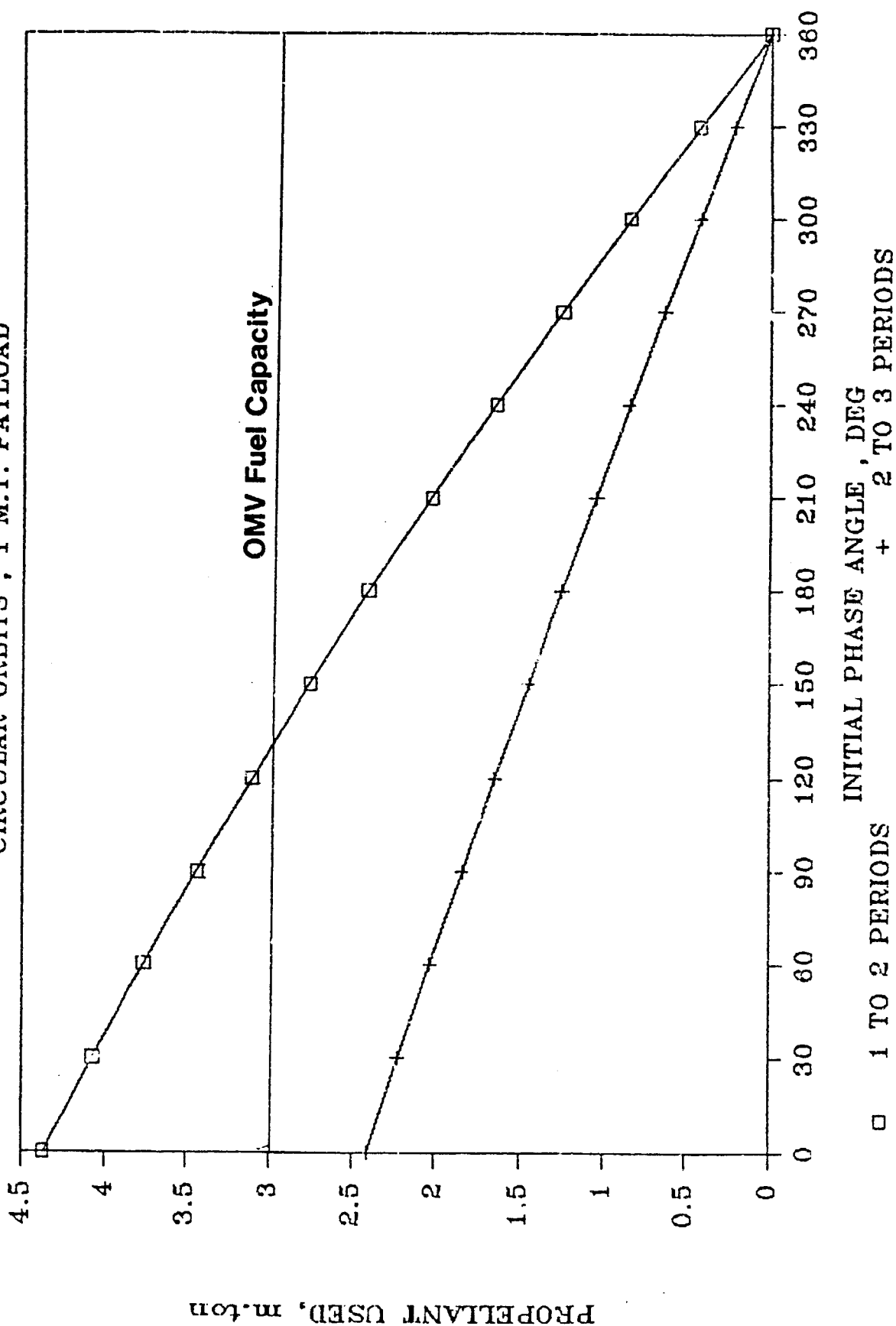
Prox. Ops. time is the time to close the last 10 or 20 Km and actually capture the target. Prox. Ops. time could probably be kept to a few hours.

6.5 Retrieval of an All Propulsive Vehicle from a High Elliptical Orbit

If propulsive braking is required, the sample would probably end up in a high elliptical orbit at Earth. Orbit periods of 12 and 24 hours have been proposed. A 12 hour ellipse is a 500 x 40,000 km orbit, while the 24 hour ellipse is a 500 x 70,000 km orbit. The 12 hour ellipse requires nearly 2.5 km/sec less delta V than deboosting into a 500 km circular orbit. The 24 hour ellipse saves another 300 m/sec or so.

Figure 18

OMV PROPELLANT USED CIRCULAR ORBITS, 1 M.T. PAYLOAD



6.5.1 Maneuver Sequence for High Elliptical Case

Figure 19 illustrates the maneuver sequence for catching a target in a high ellipse.

Time 1 is the starting time at which the target passes perigee and finishes the deorbit burn. The Maneuvering Vehicle is in its circular orbit at (about) perigee altitude.

At Time 2 tracking and plane change have been completed and the MV parking orbit has been adjusted to include the perigee point of the high ellipse.

At Time 3, the next passage of the MV through this perigee point, the MV boosts into an intermediate ellipse such that it will return to the perigee just as the target is passing through.

At Time 4 the MV and the target reach the perigee point at the same time and the MV accelerates to match velocities.

6.5.2 Time to Rendezvous for High Elliptical Case

Maneuvering time from Time 1 to Time 4 is equal to one period of the target ellipse.

Total rendezvous time = Maneuver time + Prox. Ops. time.

6.5.3 Delta Vs for High Elliptical Case

Figure 20 gives the total delta V required to rendezvous with the target and return to the 500 nm circular orbit as a function of target apogee altitude.

6.5.4 Propellant Required for High Elliptical Case

Figure 21 translates this to round trip propellant that would be used by the Centaur carrying a 1 MT payload. This is within the fuel capacity of the Centaur, but is nearing a full load.

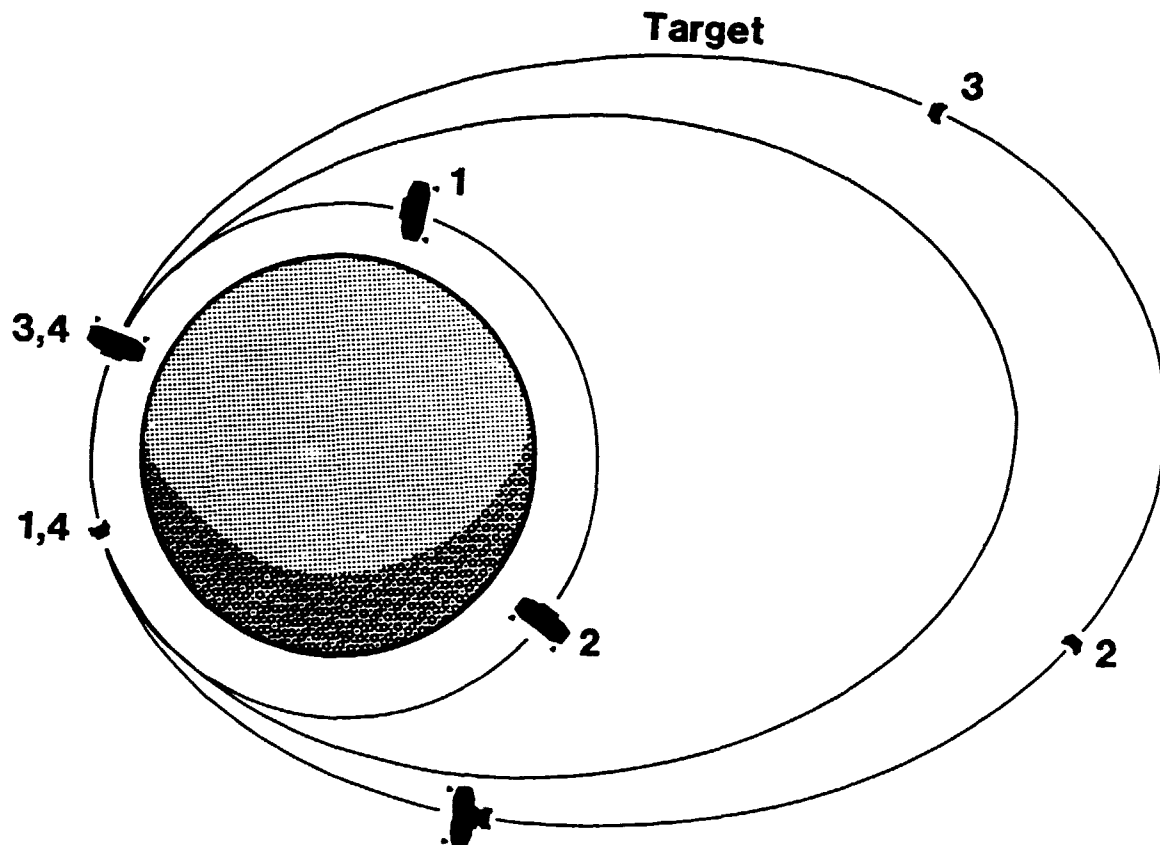
6.6 Summary of Results for Low Circular and High Elliptical Cases

- O For samples returned to low circular orbit, a rendezvous time of 6 to 8 hours may be possible.
- O For high elliptical return orbits, the minimum rendezvous is one (elliptic) orbit period plus 3 to 4 hours.
- O Retrieval by the OMV requires the sample to be returned to low circular orbit.

Figure 19, Maneuver Sequence for Elliptical Parking Orbits

Target in Elliptical Orbit

Minimum ΔV Sequence



Time 1 Target passes Perigee

Time 2 Tracking & Plane Change Completed

Time 3 $\Delta V-1$ MV boosts into Intermediate Ellipse so that Target & MV arrive at Perigee together

Time 4 MV matches Velocity with Target

● Total Maneuver time = 1 orbit of Target Ellipse

● Total Time = Maneuver Time + Prox Ops Time

Figure 20

MINIMUM INTERCEPT DELTA-V ELLIPTICAL ORBITS

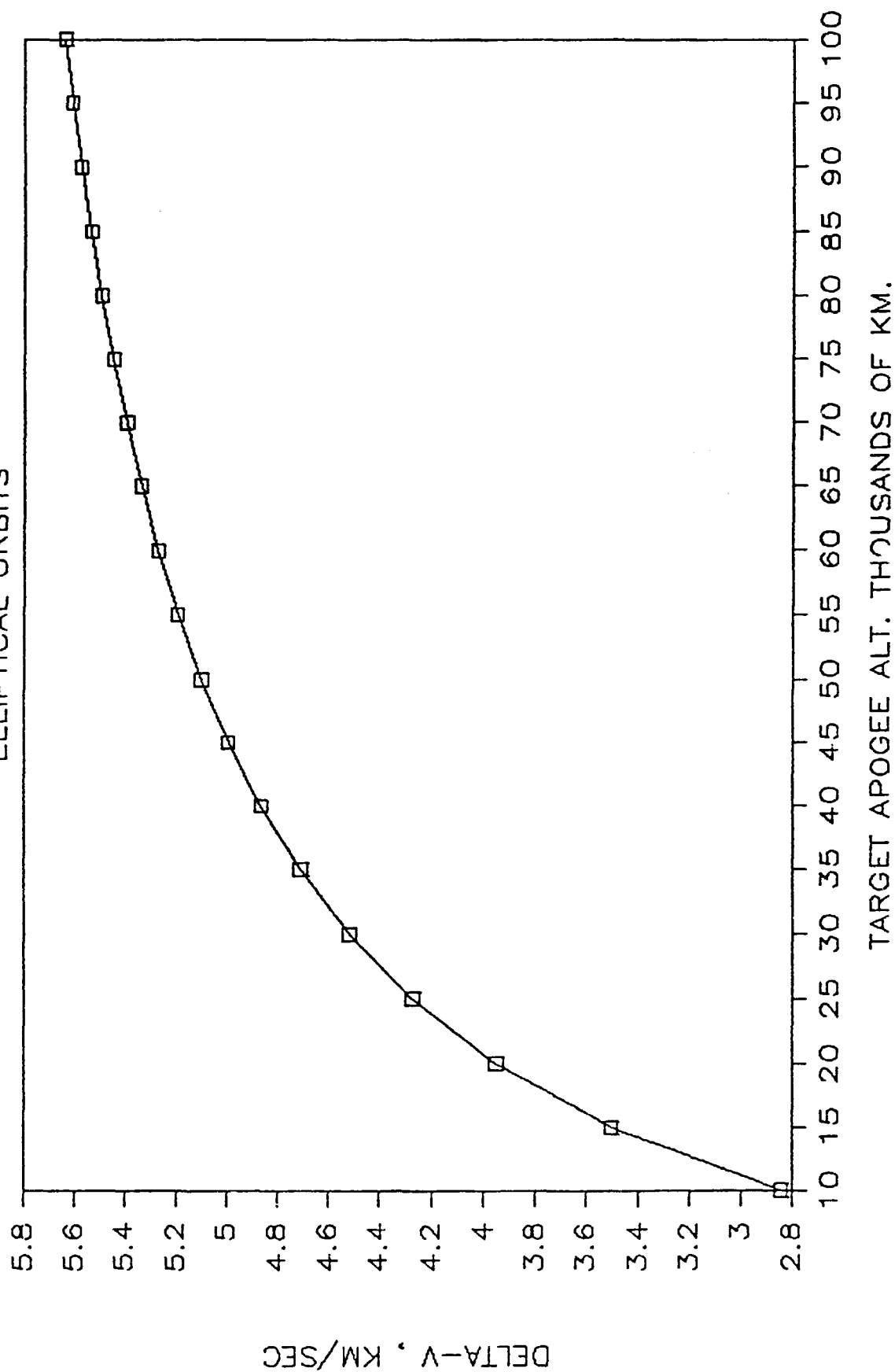
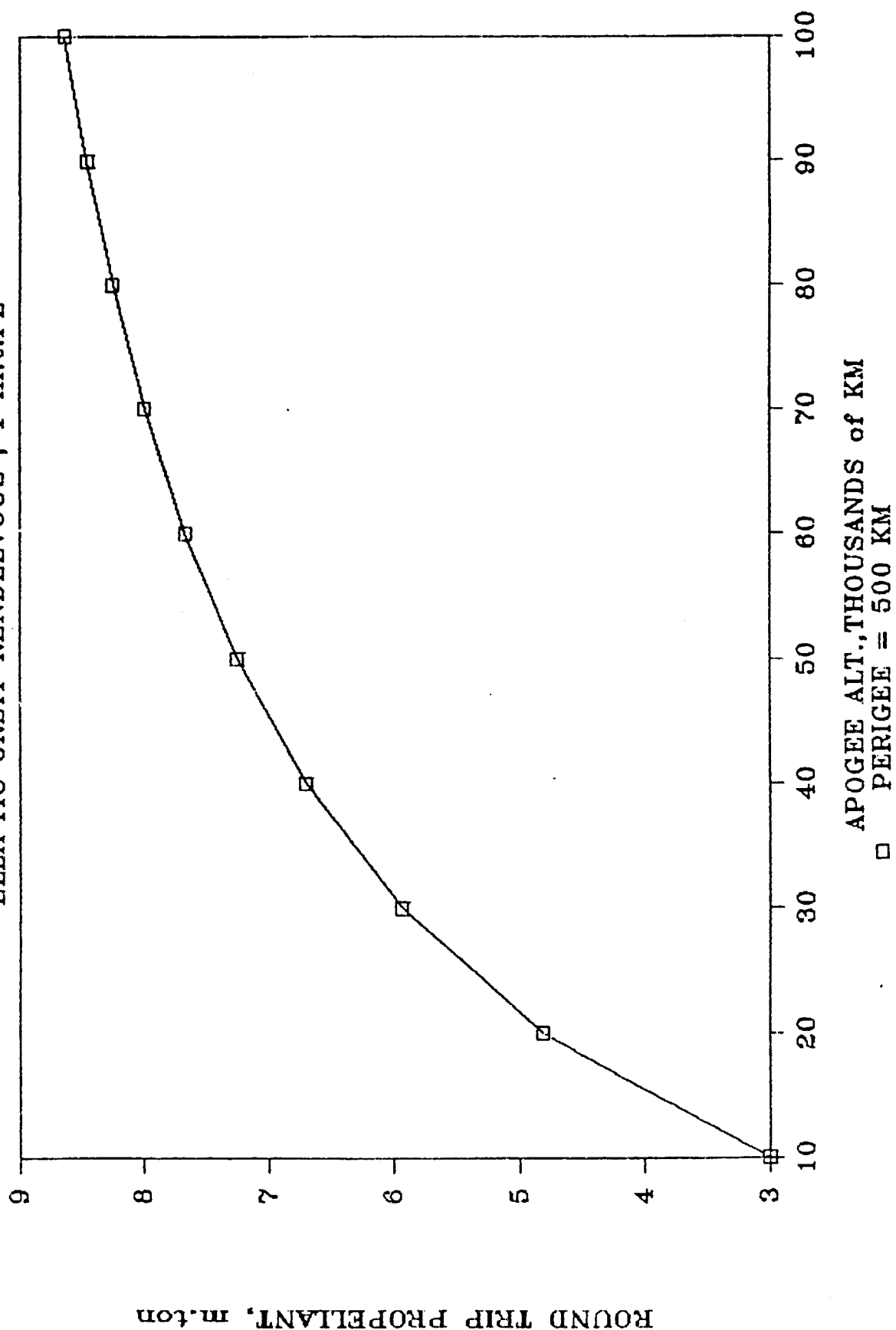


Figure 21

CENTAUR PROPELLANT USED

ELLIPTIC ORBIT RENDEZVOUS, 1 m.t.PL



- O A Centaur or OTV class vehicle is necessary for retrieval from a high elliptical orbit.
- O A low circular orbit implies aerobraking of the sample return probe. Thus, a Centaur or OTV class vehicle is necessary for retrieval of a propulsively braked sample.

6.7 Plane Change Requirements for Recovery of the Sample from High Elliptical Orbit

The previous analysis assumed all in-plane operations. However, the proposed Space Station orbits and Shuttle parking orbits have high regression rates of the ascending nodes of around $6^\circ/\text{day}$ due to the Earth's oblateness. At the same time, the proposed high capture ellipse (12 to 24 hr. periods) for returning planetary samples have comparatively low regression rates of less than $1^\circ/\text{day}$.

Thus, a recovery vehicle (Centaur, OTV, etc.) departing from the Space Station to recover the sample will be faced with a substantial plane change upon return due to this differential regression even if the orbits were initially coincident.

The following section examines the magnitude of this problem:

Figure 22 gives the regression rates for elliptical orbits at 28.5° and 56° inclinations as a function of apogee altitude. Perigees of 500 and 700 km are shown. For the higher ellipses, the regression rates have essentially vanished compared to the low circular case. Regression rates at 56° are only about two-thirds of what they are at 28.5° .

Figure 23 gives the regression rates for circular orbits as a function of altitude for 28.5° and 56° inclinations.

Figure 24 gives the actual angle between the orbit planes of a 12-hour elliptic orbit and the Space Station orbit as a function of time starting with the two planes coincident. Both 56° and 28.5° inclinations are shown. The maximum angle reached is twice the inclination returning to zero as the faster low orbit "laps" the other orbit and they become coincident again. The plane angle shown here is the plane change necessary to go from one orbit to the other. A 180° plane angle would be two coincident planes with the two vehicles going in opposite directions.

Figure 25 gives the time it takes for an elliptic orbit to come back in plane with the Space Station due to differential regression rates. The Space Station is in a 500 km circular orbit. Both orbits are at 28.5° inclination.

Figure 22

ELLIPTIC ORBIT REGRESSION RATE

PERIGEE ALTITUDE = 500 KM.

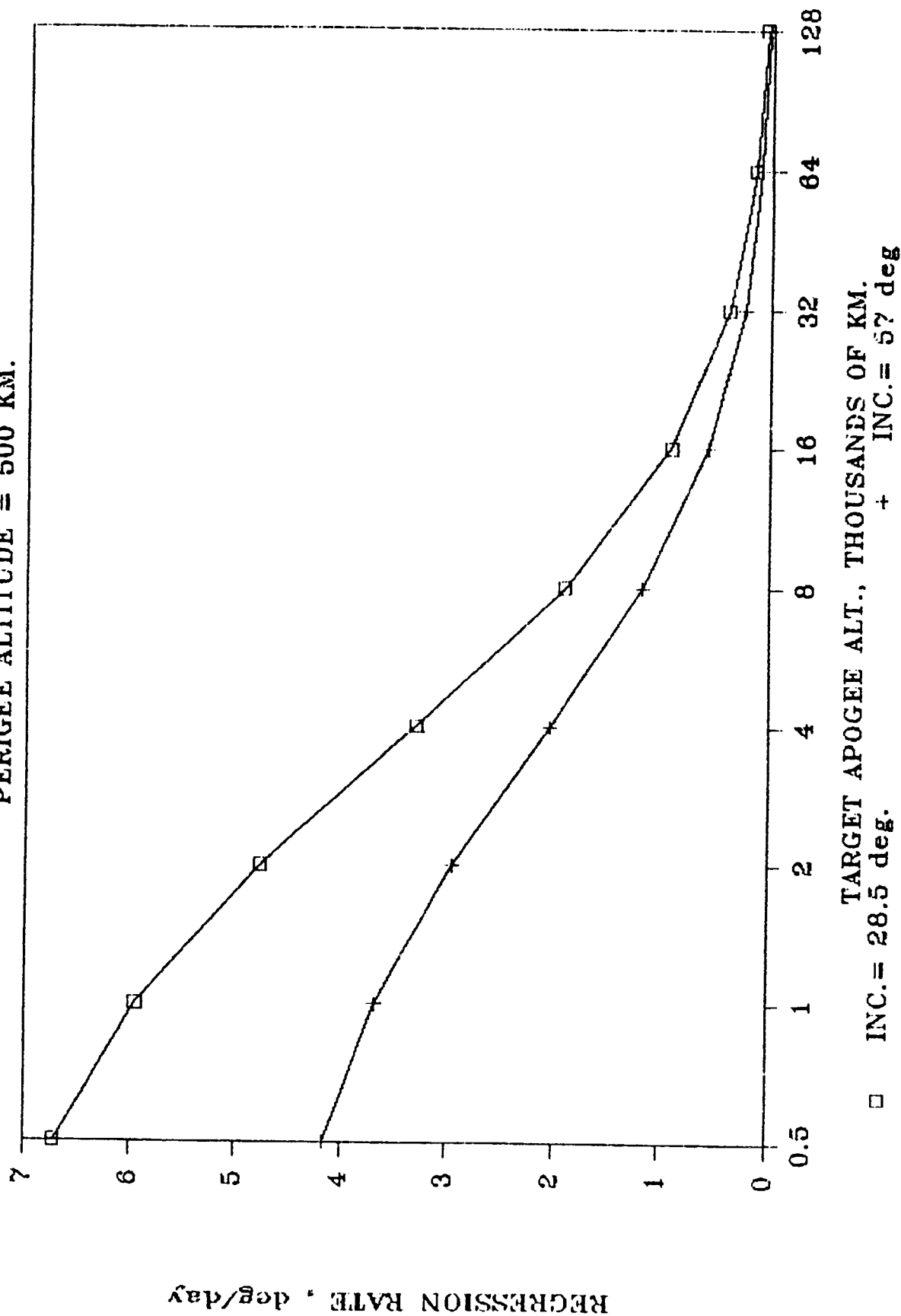


Figure 23

ORBIT REGRESSION RATE CIRCULAR ORBITS

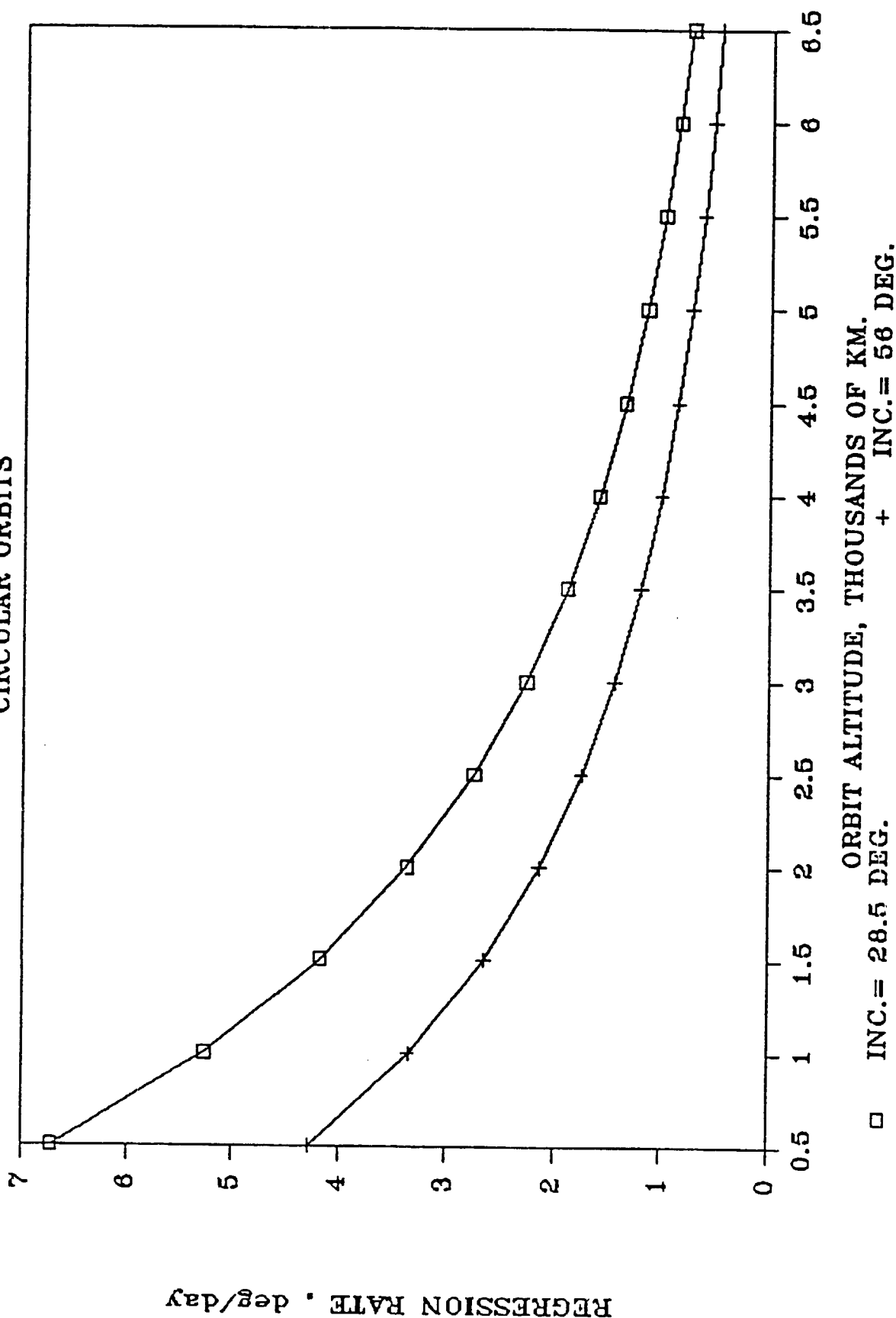


Figure 24

PRECESSED ORBIT PLANE ANGLE BETWEEN 12 HR. ELLIPSE & SS ORBIT

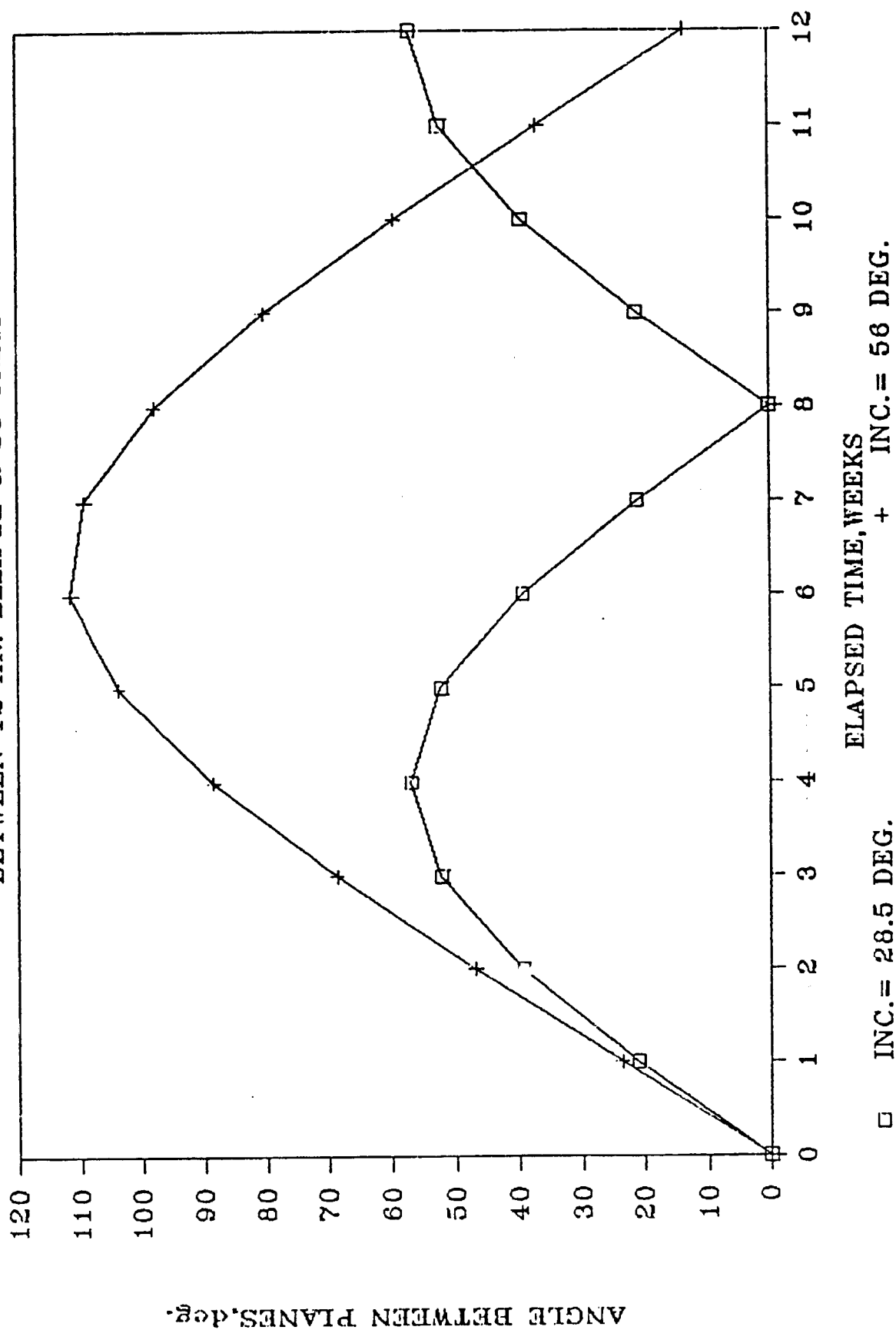
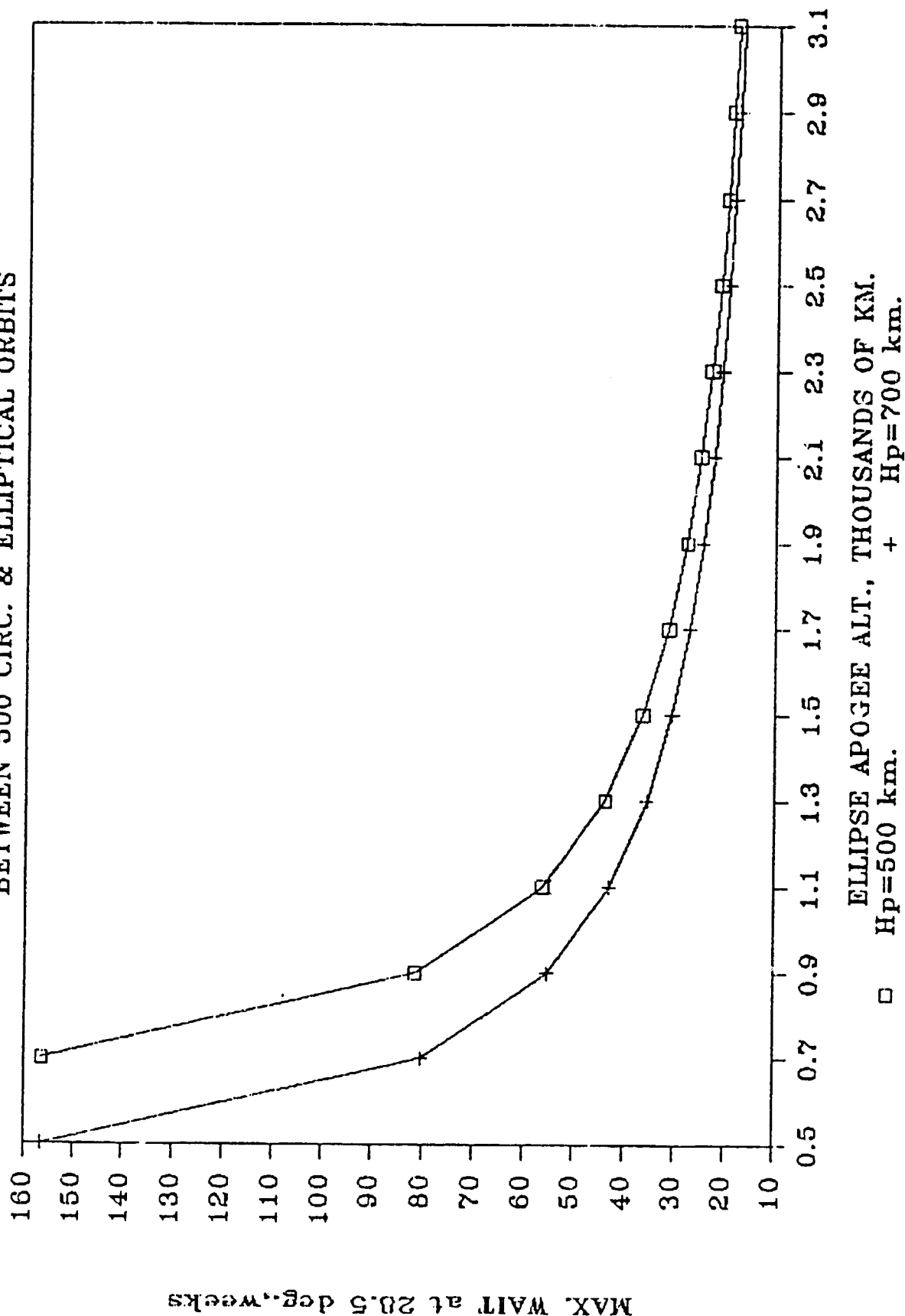


Figure 25

INTERVAL FOR ORBITS TO COME IN PLANE BETWEEN 500 CIRC. & ELLIPTICAL ORBITS



Operating from a Space Station to Shuttle, an OTV deployed to rendezvous with a sample in a high ellipse (12 hr. or more) begins to precess out of plane with the Space Station at $\sim 3^\circ/\text{day}$ as soon as it boosts into the ellipse.

Since rendezvous, recovery, and return will take at least a couple of days and possibly up to a week, there will be a plane change on return of from 10 to 20 degrees.

Three methods are available to return to the base plane:

- A. The ellipse can be lowered to a 200 km circular orbit reversing the differential regression rate. Approximately a one week wait at 200 km is required for each day spent in the ellipse based on the 500 km Space Station orbit. This option is not practical for the case in which the Shuttle deploys the Centaur directly and retrieves the sample. The Shuttle is limited to a week or so in orbit.
- B. Wait in the ellipse until the two orbits precess 360° relative to each other back into the same plane. This takes 8 weeks at 28.5° inclination or 13 weeks at 56° .
- C. Use propulsive plane change.

The cost of a propulsive plane change depends on the position of the line of apsides. As Figure 26 shows, if apogee lies on or near the junction of the two orbits, very little ΔV is necessary for a plane change in a high ellipse.

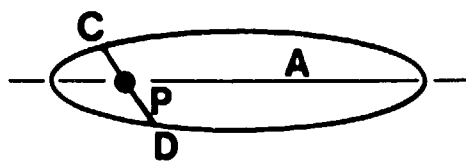
However, the position of perigee (and hence apogee) depends upon C3 and Δt , the declination of the V_∞ vector for the incoming sample probe. Little management of this position will be possible because of the constraint to initially be in plane with the Space Station.

The worst case is where apogee is 90° from the line of the plane intersection and the plane change must be made at the semi-latus rectum point. For this case after a 3 day wait (10° plane change) the ΔV for simply changing the plane is ~ 1.1 km/sec. For a LO_2/H_2 stage such as Centaur or an OTV this means an increase in total weight of ~ 28 percent as extra fuel. For a Centaur with a 1 MT payload this would mean an increase in fuel load of about 3 MT. This increase would probably be acceptable.

Differential precession will increase the propellant requirements for retrieval from a high ellipse by up to 30 percent.

Figure 26, Position of the Line of Apsides

1.

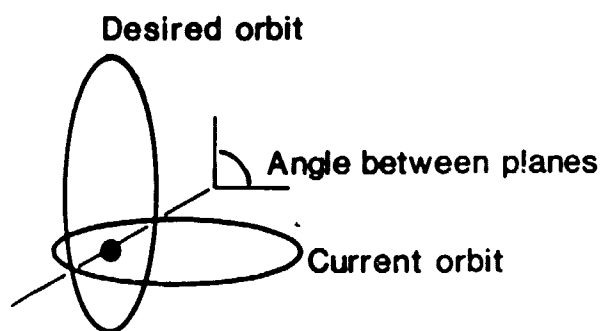


A • Line of apsides

P • Line of intersection of the planes

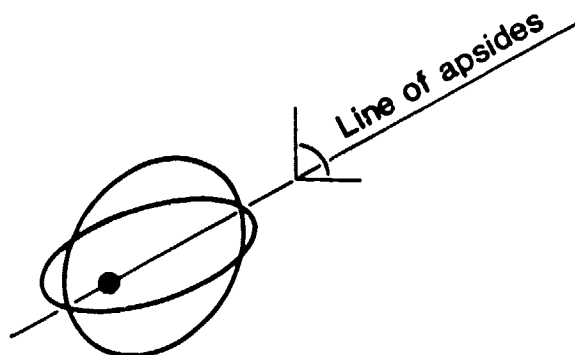
C&D • Points at which plane change can be made

2.



Worst Case

3.



Best Case

7.0 Sample Transport Container Conceptual Design

A common element in all the return options is a container to transport the returned spacecraft/sample. There is some debate as to what must be biologically isolated and returned to Earth the entire spacecraft, the spacecraft less aeroshell (which re-enters), or just the small container with the sample in it. The biological risk associated with each of these options must be assessed to determine the best way to isolate and return the sample and perhaps the spacecraft.

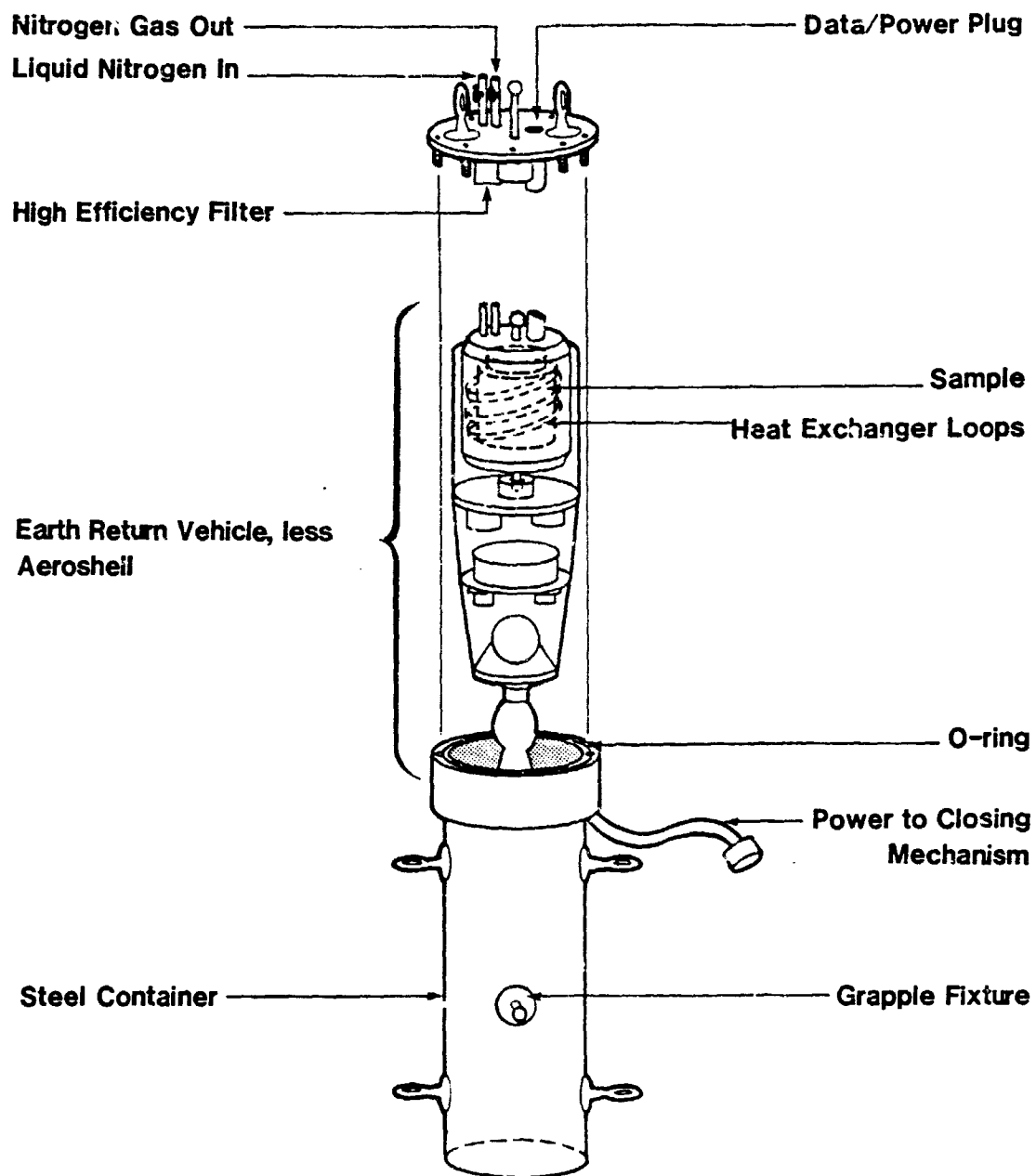
In the absence of this risk information, a baseline case was chosen. The baseline is the case in which the sample is aerobraked into Low Earth Orbit, the aeroshell is ejected and re-enters, the sample/remaining spacecraft is circularized in Low Earth Orbit and retrieved in its entirety to be eventually placed in the container shown in Figure 27 at the Space Station. In terms of Space Station handling, the fifth option, in which the sample is retrieved to the Space Station and a small sample is then removed from the larger and minimal analysis performed, was chosen as the baseline for the conceptual design of the container. Figure 27 is a conceptual design for this container. Figure 28 shows how this container might fit in the Shuttle cargo bay.

The container must provide thermal control for the sample. The controlled environment of the sample transport container is to be a hard vacuum with the temperature of the sample maintained in the range of 100 to 130 degrees Kelvin. However, the length of time available for recovery without exceeding the temperature limit of the sample has not been determined. Therefore, the capability of providing additional thermal conditioning for the sample when the sample canister assembly is initially recovered in orbit is considered. This capability, which supplements that provided by the Earth Return Vehicle, requires that some mode of cooling be attached to the sample canister assembly as soon as practical after rendezvous with the recovery vehicle, the OMV or OTV.

A number of techniques for providing this additional thermal conditioning have been considered and will be discussed briefly in this report. A technique was identified that offers the most expeditious method, provided certain interface capabilities are provided by the Earth Return Vehicle design. This preferred approach is shown in the attached sketches. The preferred approach is to adaptively utilize the capabilities that others will provide, necessarily, for the Earth Return Vehicle and the sample canister assembly to control, measure, and record the sample temperature during its return from the site of sample collection.

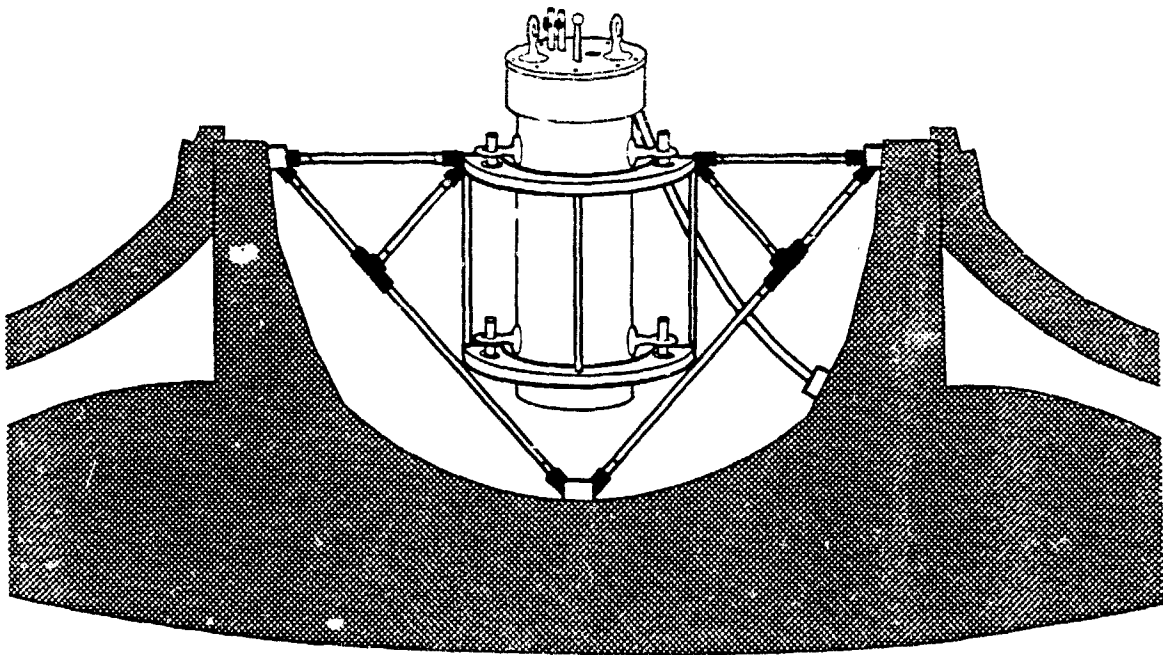
It is obvious that the components which satisfy similar requirements in the vicinity of the Earth could be the same as those on the Earth Return Vehicle, if those components remain with

Figure 27, Transport and Handling Container



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**Figure 28, Transport and Handling Container
in the Payload Bay**



the sample canister assembly after separation of the two crafts. Those components include the instrumentation, data processing, and data recording devices, thermal insulation, temperature controls, and heat exchangers. It is anticipated that these components can remain with the sample canister without substantial weight penalty. It is also anticipated that the program costs will be reduced by the "common" use of components in the manner shown in the attached sketches.

Thermal insulation of the sample canister assembly should equal that of the 15 layer aluminized Mylar with honeycomb nylon net as a separator which was reported to have an effective epsilon of from .0038 to .0018 depending on the closure stitch. This configuration was used by JPL during the Mariner 9 program and should not be a weight penalty for this application. Insulation, support, instrumentation, and penetration heat leaks should be less than five watts during the circular orbit which would be the worst case with respect to heating when compared to the elliptical orbits.

The sample canister assembly's shell or an analogous heat exchanger surface should be traced with tubing to transfer heat from the sample to the active cooling loop of the Earth Return Vehicle "stack". The addition of interface connectors which would permit adding a liquid nitrogen (approximately 100°K) supply could "rejuvenate" the retained system and permit extended operational time without exceeding the temperature limits. Thus the resupply of a cryogenic fluid, such as liquid nitrogen, is the preferred approach because of the relative simplicity, the use of "common" equipment, and the probable availability of liquid nitrogen on the Space Station. While the added complexity necessary to interface this supply autonomously during rendezvous is not desirable, the advantage of extending the useful life of the sample canister environmental control system without adding to its weight for "outbound" configuration is adequately offsetting.

The liquid nitrogen may be filtered when coming into the heat exchanger and when venting by high efficiency particulate filters such as are now used in labs like the CDC's for air.

Thus by configuring the sample canister assembly so that a supply of liquid nitrogen can be attached after rendezvous near Earth, the life of the systems which will be necessary for thermally conditioning the sample during the "inbound" configuration can be extended. The systems of the sample canister assembly to be retained in a useful condition would be the insulation, heat exchanger, flow control valves, control logic, and data systems. With this provision, the capability for 10 to 20 days of environmental conditioning after retrieval near Earth could be provided at a weight penalty of 210 kg to the OMV/OTV as shown in Table 6.

TABLE 6, OMV/OTV ONLY

ITEM	WT Kg
1) Liq. N ₂ Tank, Insulation, Valves, Plumbing, Supports	6.4
2) Nitrogen	21.6
3) Manipulators 2 Ea.	25
4) Manipulator Power Supply	50
5) Manipulator Motors	50
6) Misc. End Effectors, Supports, Etc.	15
Subtotal	168
7) Plus 25% Contingency	42
Total	210

TABLE 7, SPACE STATION ONLY

ITEM	WT Kg
1) Refrigerator	18.3
2) Plumbing	5.7
3) Pump	5
4) Heat Exchanger	9
5) Connectors & Valves	5
6) Power Supplies	50
7) Mounts, Controls, Misc.	22
8) Manipulators 4 Ea.	50
9) Manipulator Power Supply	50
10) Manipulator Motors	50
11) Supports and Feedthroughs	50
12) Data Systems	10
Total	325

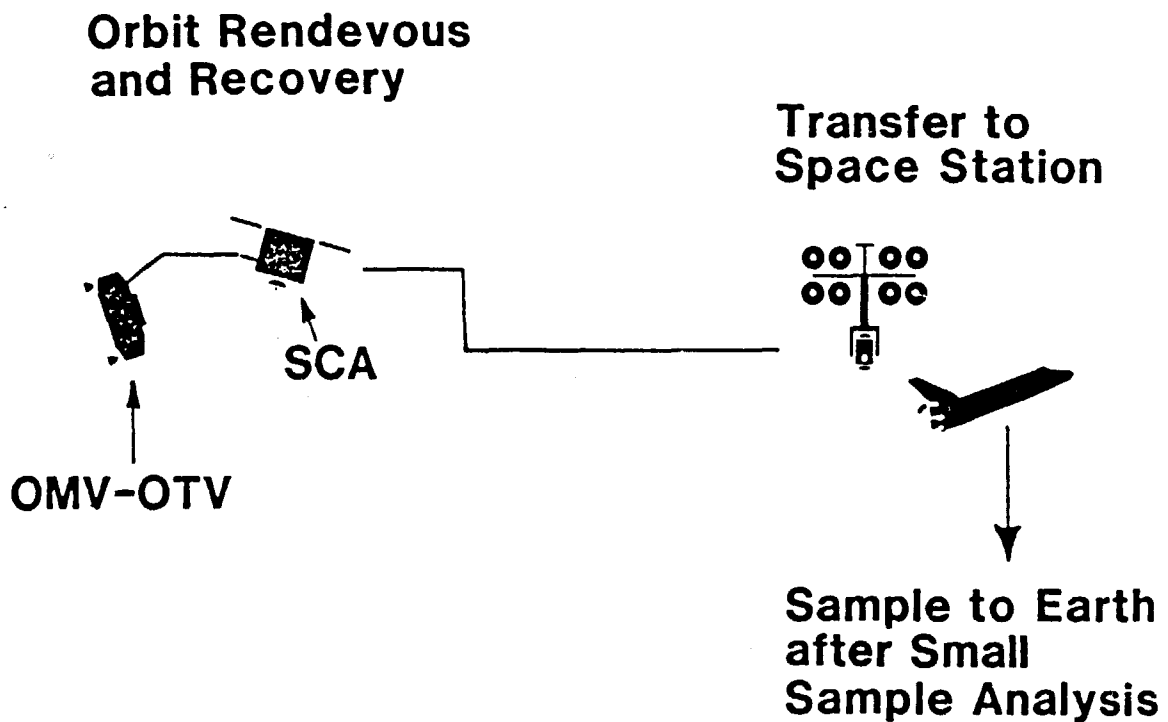
The preferred scenario is depicted in Figure 29, and the configuration for interfacing with the sample canister assembly (preferred concept) is shown in Figure 30. In a manner similar to the preferred concept, the same system components of the sample canister assembly also can be used on the Space Station by interfacing a refrigerator or some coolant flow device at the same connector. This interface is sketched in Figure 31 and requires that an adapter be attached to an airlock to hold the sample canister assembly and the manipulators that would be used for sample handling. Four manipulators are considered, although fewer might satisfy requirements as they become better identified. The samples could be maintained at hard vacuum in the airlock and the multilayer insulation would limit heat leaks to an acceptable level.

Table 7 is a weight statement for this Space Station equipment shown in Figure 31.

The refrigerator that is proposed is oversized for the anticipated heat leak, allowing handling with some latitude for keeping the sample within the temperature range. The refrigerator would be a stirling cycle that is equivalent to the Malaker Corporation Cryomite, Mark VII-R. Some of its specifications are shown in Table 8.

Figure 29

Preferred Mission Scenario



After Separation from the Earth Return Vehicle

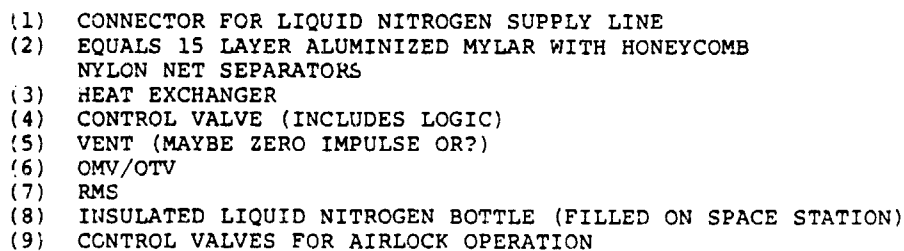
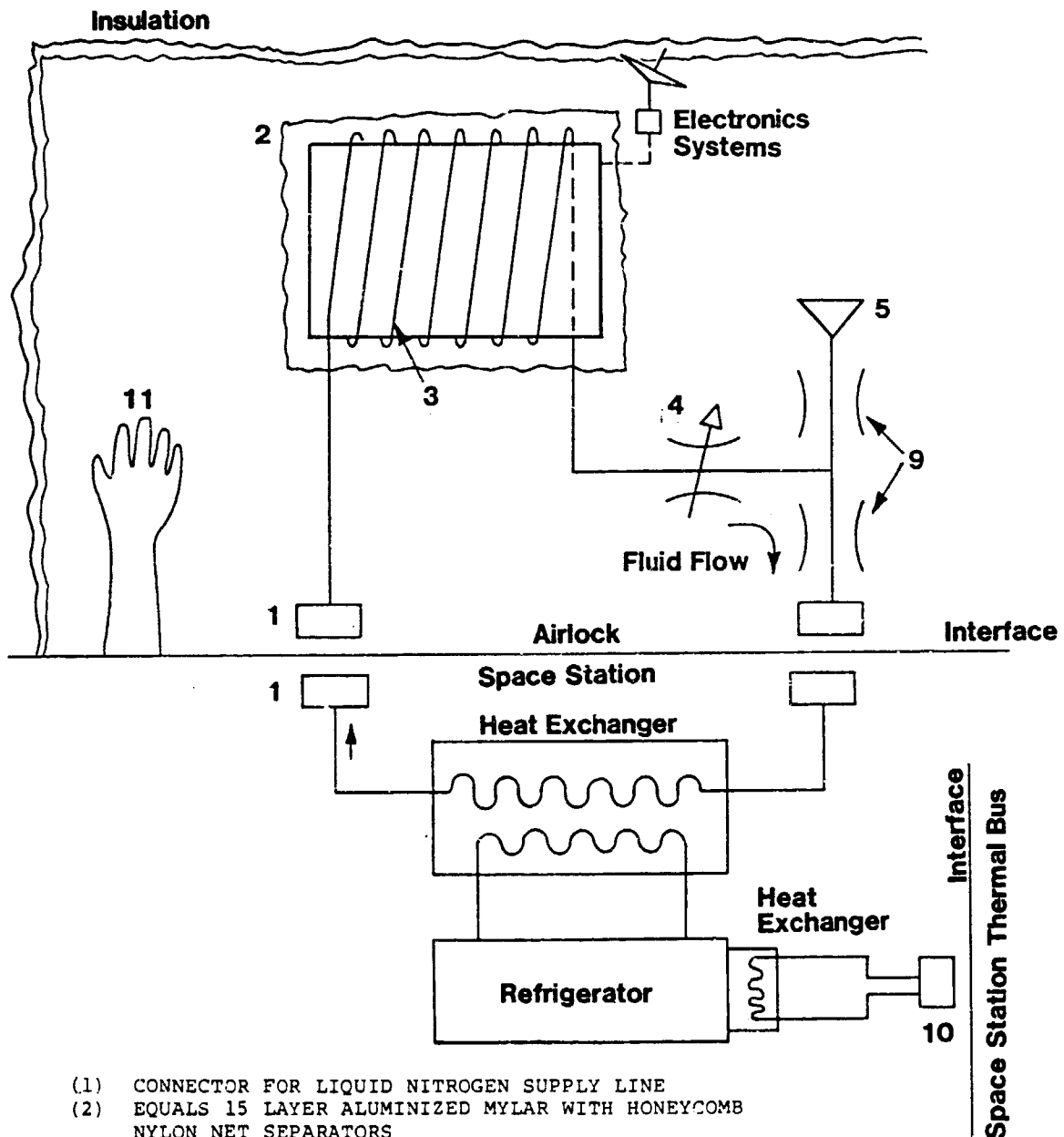


Figure 31, Interface with the Sample at the Space Station

After Attaching to Airlock



- (1) CONNECTOR FOR LIQUID NITROGEN SUPPLY LINE
- (2) EQUALS 15 LAYER ALUMINIZED MYLAR WITH HONEYCOMB NYLON NET SEPARATORS
- (3) HEAT EXCHANGER
- (4) CONTROL VALVE (INCLUDES LOGIC)
- (5) VENT (MAYBE ZERO IMPULSE OR?)
- (9) CONTROL VALVES FOR AIRLOCK OPERATION
- (10) MECHANICAL COMPRESSION THERMAL CONTACT FITS SPACE STATION OR SHUTTLE FOR HEAT REJECTION
- (11) MANIPULATORS, TYPICAL 4 PLACES

TABLE 8, Space Station Refrigerator

Cryomite, Mark VII-R, Malaker Corp. or Equivalent

Stirling Cycle	
Temperature Kelvin	100
MTBF Hrs.	40,000
Cooldown Time Mins.	3.8
Refrigeration Watts	90
Power Input KW	1.22
208/3 Phase/400 Hertz	
COP	.0738
Percent Carnot	11.7
Weight Kg	18.2
Volume M ³	.01283

Finally, the transport by the Shuttle to Earth and to the depository by ground transport can be accomplished by encasing the sample canister assembly in a vacuum chamber while still providing coolant flow through the interface as on the Space Station. In other words, by maintaining the vacuum external to the sample canister assembly, the rest of the systems are the same for all practical purposes. This encasement also provides some biological isolation. This isolation was provided by the airlock adapter on the Space Station as a secondary objective. Figures 27 and 28 show a concept for this container if the entire spacecraft is to be returned. If only the sample canister is returned, it may be possible to reduce the size of this container and associated equipment such that it will fit in the mid-deck.

Biological risk may dictate that the entire Earth Return Vehicle be returned to Earth in a Transport and Handling Container, such as shown in Figures 27 and 28. This container must be very rugged, hold a vacuum, and possibly be able to survive Shuttle accidents intact. The container shown in Figure 27, if built with two inch steel, might weigh 7 metric tons. Other metals may be more appropriate. Crash protection might require it to be much larger than shown with internal honeycomb to protect the sample from impact and external thermal protection for various accident scenarios. In any event, it could easily become massive.

Other approaches for thermal control that were considered were radiators and other thermodynamic cycles such as Ericsson (Brayton), Claude/Collins, Gifford-McMahan, and Vuilleumier. For this application it is believed that low power and reliability are the primary drivers, hence the Stirling Cycle with its dependability record was chosen. The heat driven Vuilleumier Cycle, separable systems such as the Gifford-McMahan, and the air-bearing Brayton Cycle were not deemed best suited for this purpose.

Radiator concepts require analysis that is beyond the scope of this effort before a reliable system concept could be proposed.

Another alternative was to duplicate the capabilities inherent to the Earth Return Vehicle assembly requirements. The added weight and cost which would result from this duplication are significant, and it is believed that design trade studies will show the benefit of utilizing the system of the Earth Return Vehicle for near Earth as well as the "inbound" phase of this mission. The removal of insulation and other equipment around the sample on-orbit in order to install new equipment would also be difficult and perhaps biologically risky.

In conclusion, the best approach for providing thermal control of the sample, if thermal control is needed after rendezvous, is to use the systems that will be used for thermal control during the "inbound" phase of the Earth Return Vehicle. Those systems can be used by resupplying the cryogenic fluid, such as liquid nitrogen, to the coolant loop. The other systems such as insulation, fluid flow control, data records and processing, and heat exchangers would continue to operate as before.

8.0 References

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**Table A-1, Comet Nucleus Sample Return Weight Statement
Aerobrake to Leo Option
(Taken from Ref. 5)**

VEHICLE

<u>Subsystem/Element</u>	<u>Mass (Kg)</u>	<u>Remarks</u>
Sample Canister Assy. (SCA)		
Sample	10.0	
Hollow drill bits (4)	4.0	
Sample Retainer Block	0.7	
Inner container w/therm.ins.	2.8	
Temp. & Presssure sensors	0.4	
Umbilical connector	0.1	
Canister shell w/gasket	4.3	
Canister thermal insulation	1.3	
Cover, seal mech., lid assy.	3.2	
Lid hinge, drive, motor assy.	0.8	
Seal drive motor	0.5	
Lid latch mechanism	0.4	
Retention fixture	0.2	
Handle	0.4	
Cabling	0.5	
Subtotal:	29.6	
Contingency:	3.6	
TOTAL:	33.2	
Earth Aerocapture Capsule (EAC)		
Telecom. +Telem. Unit	1.6	8b/s downlink only, omni antenna
PWR: Solar array	1.5	Body mtd., GaAs, 0.5 m ²
Batteries	3.9	NiH, 171 W-hours
Condg./Ctl./Distrib.	2.4	
Guid.&Ctl.:		
Sun sensor (3)	0.6	V075 acquis.s/s
Accelerometer w/electr. (3)	4.8	GLL
IMU	5.4	Honeywell, intern.redund.
Processor (2)	1.2	GLL, CRAF
Memory (2)	3.3	CRAF
I/O Electronics (2)	3.2	1/3 of CRAF
Drive Electronics	2.6	1/2 of CRAF
Power Supply (2)	2.4	GLL, CRAF
Flap actrs. (2)	6.0	New
Thermal Control:		
Insulation	3.0	
Radiator, coolant plumbing	5.2	
Struc. & Mechanisms:		
Grappling knob	0.5	
SCA monit. contact assy.	0.7	

Table A-1 (Continued)

VEHICLE

<u>Subsystem/Element</u>	<u>Mass (Kg)</u>	<u>Remarks</u>
EAC (Continued)		
Cover/aft heat shield	8.1	
Cover open/close mech.	2.4	
SCA retent./release dev.	0.3	
Aeroshell release dev. (3)	2.1	
Bus and struc. supports	14.2	
Aeroshell	81.2	per G.E. "generic" study, mostly carbon phenolic
Flaps backing plate	6.8	2 mm Nb
Subtotal:	161.5	
Contingency:	19.4	
Total:	180.9	
+SCA	33.2	
Total EAC + SCA (dry):	214.1	
RCS: Inerts and supports	1.8	30% of MM69, also used for
Propellant (N ₂)	0.9	SCA cooling
Thruster assys. (4)	4.2	incl. 2 on aft heat shield
Regul., valves, plumbg.	1.8	incl. for aft ht.shld.
Total EAC + SCA (wet):	222.8	
ORBIT CIRCULARIZATION PROP.:		
Inerts and supports	1.1	One Star-6 SRM
Safe/arm box	2.2	Shuttle reqmt.
Propellant	4.1	for 100 m/s
Total EAC w.PROP + SCA:	230.2	

**Table A-2, Comet Nucleus Sample Return Weight Statement
Modified for Direct Entry**

VEHICLE

<u>Subsystem/Element</u>	<u>Mass (kg)</u>	<u>Remarks</u>
Total EAC w.PROP + SCA:	230.2	
Equipment removed from Aerobraked to LEO vehicle:		
Orbit circularization propellant & hardware	-7.4	
Flap backing plate	-6.8	
Aeroshell	-81.2	
Aeroshell release devices	-2.1	
Grappling knob	- .5	
Flap actuators	-6.0	
Equipment added for Direct Entry:		
Ablator heat shield	248	76.26 kgms/m ² x 3.25 m ² Phenolic nylon
Subtotal	374.2	
Parachute and mechanisms	15.0	4% of subtotal
Direct Entry Vehicle Total	389.2	
Direct Entry Vehicle Total with 50% better heat shield	260.2	50% of ablator heat shield removed

Table A-3, Aerobraked Mars Sample Return Weight Statement
(Taken from Ref. 6)

VEHICLE

<u>Subsystem/Element</u>	<u>Mass Pwr</u> <u>(kg)</u>	<u>Remarks</u>
NOTE: Mass contingency is based on assumption uncertainty and ranges from 3 - 8% for electronic equipment to 13 - 18% for structures. Power contingency is 15% of total.		
Sample Canister Assy. (SCA)		
Sample	5.0	
Sample vial assys. (19)	1.4	
Teflon Retainer Block	0.8	
Inner container w/therm.insul.	1.8	
T & P sensors	0.3	(EAC power)
Slip ring assy.	0.4	
Canister shell w/gasket	2.6	
Canister therm. insulation	0.6	
Cover, seal mech., and lid assy.	1.6	
Lid hinge, drive, motor assy.	0.8	*(EAC bat. power)
Seal drive motor	0.4	* " " "
Lid latch mechanism	0.4	* " " "
Grappling shafts (2)	0.7	
Wiring, connectors	0.4	
Subtotal:	17.2	
Contingency:	2.8	
Total	20.0	
Earth Aerocapture Capsule (EAC)		
Telecom. +Telem. Unit	1.6	8 b/s dwnlk.only,omni ant.
PWR & Pyro: Solar array	1.5	Body mtd., GaAs, 0.5 m ²
Batteries	2.3	NiH, 63.7x1hx1.5/0.8=101 Wh
Condg./Ctl./Distrib.	3.4	
Pyro Unit (2), squibs	3.6	CRAF
Guid. & Ctl.:		
Sun sensor	0.8	CRAF
Accelerometer	0.7	SOTP
Inert.Ref.Unit	10.0	SOTP (FORS)
Processor (2)	1.2	CRAF (includes Memory pwr.)
Memory (2)	3.3	CRAF
I/O Electronics (2)	3.2	1/3 of CRAF
Drive Electronics	3.6	70% of CRAF
Power Supply (2)	2.4	CRAF

Table A-3 (Continued)

VEHICLE	Mass Pwr	
<u>Subsystem/Element</u>	<u>(kg)</u>	<u>Remarks</u>
EAC (Continued)		
Thermal Control: Insulation	1.4	
Radiator	1.1	
Struc. & Mechanisms:		
SCA brush-contact assy./supt.	1.2	
SCA retent./release dev.	0.5	
Aeroshell release dev. (3)	2.1	
Cable/tubing cutter	0.3	
Bus and struc. supports	11.5	
Cabling	3.8	
<u>Subtotal:</u>	<u>59.5</u>	
Contingency:	6.6	
<u>New Subtotal:</u>	<u>66.1</u>	
+ SCA	20.0	
Subtotal w. SCA:	86.1	mass to be orbit-cir- cularized
ORBIT CIRCULARIZATION PROP.:		
Inerts and Supports	0.9	for 100 m/s
Safe/arm box	2.2	
Propellant	3.1	
Subtotal (Veh.+PROP+SCA):	92.3	(after aeroshell jettison)
AEROSHELL SYSTEM:		
Aeroshell w/flaps	24.0	mostly carbon phenolic
Flap actuators (2)	2.6	VO75 gimbal actrs.
Flaps backing plate	4.0	1.2 mm Nb
Cover/aft heat shield	2.4	
Cover open/close mech.	1.6	
Cover omni antenna, coax	0.3	
Cover thruster assy. (2)	2.1	(VO75) incl. plumbing
<u>Subtotal(Aeroshell Sys.):</u>	<u>37.0</u>	
Contingency:	5.5	
New A/S Sys Subtotal:	42.5	
Total EAC + SCA(Less RCS):	134.8	
RCS: Inerts and supports	1.2	20% of M'69
Propellant (N ₂)	0.6	20% of M'69
Thruster assys. (2)	1.9	(VO75)
Total EAC only (wet):	118.5	
Total EAC +SCA (wet):	138.5	

**Table A-4, Mars Sample Return Weight Statement
Modified for Direct Entry**

VEHICLE

<u>Subsystem/Element</u>	<u>Mass (kg)</u>	<u>Remarks</u>
Total EAC w/PROP + SCA:	138.5	
Equipment removed from Aerobraked to LEO vehicle:		
Orbit circularization propellant & hardware	-6.2	
Aeroshell Sytem	-42.5	
Aeroshell release devices	-2.1	
Grappling knobs	- .7	
Equipment added for Direct Entry:		
Ablator heat shield	248	76.26 kg/m ² x 3.25 m ² Phenolic nylon
Subtotal	335	
Parachute and mechanisms	13.4	4% of subtotal
Direct Entry Vehicle Total	348.4	
Direct Entry Vehicle Total with 50% better heat shield removed	219	50% of ablator heat shield